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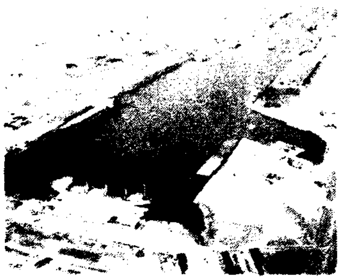

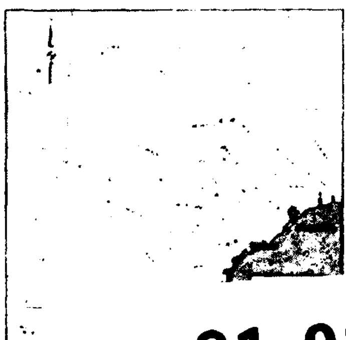

HYDRAULICS
LABORATORY

TECHNICAL REPORT HL-91-8

SHIP NAVIGATION SIMULATION STUDY BRAZOS ISLAND HARBOR 42-FOOT IMPROVEMENT BROWNSVILLE, TEXAS

by

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13. ABSTRACT *(Maximum 200 words)*

A real-time ship simulation investigation of the proposed design for deepening and widening the man-made Brazos Island Harbor Channel, Brownsville, TX, was conducted. The purpose of this study was to determine if the navigation channel could be deepened from 36 to 42 ft without widening the existing channel width of 200 ft or if the channel required widening to 250 or 300 ft as authorized. A numerical model of the existing ship channel from the Gulf of Mexico to the turning basin at the Port of Brownsville was developed. This model was verified by a member of the Brazos-Santiago Pilot's Association. Numerical models of three plans were also developed, one with the existing channel deepened to 42 ft, one with the channel widened to 250 ft and deepened to 42 ft, and the other with the channel widened to 300 ft and deepened to 42 ft. The 250-ft-wide channel had a 100-ft-wide and 15-ft-deep side channel for tow traffic. Tests were run in Brownsville on the US Army Engineer Waterways Experiment Station portable ship simulator.

These tests demonstrated that 250 ft is the optimum width for the Brazos Island Harbor Channel at a depth of 42 ft.

14. SUBJECT TERMS

Brazos Island Harbor Ship Channel	Deepwater channel	Ship
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PREFACE

This investigation was performed by the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES) for the US Army Engineer District, Galveston (SWG). The study was conducted with the WES research ship simulator during the period September 1989-March 1990. SWG provided survey data of the prototype area. Current modeling was conducted by the Estuarine Processes Branch, Estuaries Division, Hydraulics Laboratory.

The investigation was conducted by Mr. Dennis W. Webb of the Ship Simulator Group, Navigation Branch, Waterways Division, Hydraulics Laboratory, under the general supervision of Messrs. Frank A. Herrmann, Jr., Chief of the Hydraulics Laboratory; Richard A. Sager, Assistant Chief of the Hydraulics Laboratory; M. B. Boyd, Chief of the Waterways Division, and Dr. Larry L. Daggett, Chief of the Navigation Branch. Ms. Donna Derrick, Civil Engineering Technician, Navigation Branch, assisted in the study. This report was prepared by Mr. Webb and Dr. Daggett.

Acknowledgment is made to Mr. Robert Van Hook, Engineering Division, SWG, for cooperation and assistance at various times throughout the investigation. Special thanks go to the Port of Brownsville for allowing WES to use their office to conduct testing and to the Brazos-Santiago Pilots Association for participating in the study.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	metres
horsepower (550 foot-pounds (force) per second per ton (force))	83.82	watts per kilonewton
inches	2.54	centimetres
knots (international)	0.5144444	metres per second
miles (US statute)	1.609347	kilometres

Figure 1. Brownsville Channel Project Map

SHIP NAVIGATION SIMULATION STUDY, BRAZOS ISLAND HARBOR 42-FOOT IMPROVEMENT, BROWNSVILLE, TEXAS

PART I: INTRODUCTION

1. The Port of Brownsville is located at the southernmost tip of Texas, and has served southern Texas and northern Mexico since 1936. The 19-mile*-long Brownsville Ship Channel (Figure 1) provides access from the Gulf of Mexico to the Port of Brownsville for deep-draft vessels. As well as being a deepwater seaport, the Port of Brownsville is also the southern terminus of the US Inland Waterway System. Barge traffic uses the Brownsville Ship Channel as the link between the port and the Gulf Intracoastal Waterway (GIWW). Principal imports and exports of the port include chemicals, petroleum, grain, cotton, sulfur, citrus, glass, steel, ores, fertilizers, and crude rubber. Typical ships using the channel are in the 550- to 650 ft-length range. Loaded ships typically have a draft of 32 ft. An improvement project to accommodate larger and deeper vessels will allow the Port of Brownsville to support more economical transportation.

2. The present channel as maintained by the US Army Engineer District, Galveston, has the following dimensions:

Channel Segment	Depth ft	Width ft
Entrance: Gulf to Padre Island (mile -2 to 0)*	38	300
Interior: Padre Island to Goose Island (mile 0 to 12)	36	200
Harbor (mile 12 to 15)	36	300
Turning basin extension (mile 15 to 16)	36	400-500
Turning basin	36	900

* Miles are approximate.

Proposed Channel Improvement

3. The proposed improvements in the Brazos Island Harbor channel, designated as Plan 1, are described as follows (US Army Engineer District, Galveston, 1989):

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* A table of factors for converting non-SI units of measure to SI (metric) units is found on page 3.

Channel Segment	Depth ft	Width ft
Entrance: Gulf to Padre Island	44	400
Interior: Padre Island to Goose Island	42	300
Harbor	42	300
Turning basin extension	42	325-400
Turning basin	36	1,200

These depths are project depths and do not provide for advance maintenance or dredging tolerance. The depths for the proposed new channels with advance maintenance and dredging tolerance can be 3 ft deeper. The interior channels and the turning basin will be widened on the south side only. The turning basin was designed based on the assumption that all ships can be turned empty, thereby eliminating the need for dredging the turning basin to the 42-ft depth provided in the rest of the channel. These improvements will allow ships in the 750- to 780-ft-length range with drafts of 38 ft to use the harbor.

Preliminary Testing

4. Prior to conducting real-time testing with pilots, preliminary tests were conducted to determine the critical conditions to be used during real-time piloted simulation. The preliminary testing procedures, as well as the results, are discussed in a memorandum.*

Purpose and Scope of Investigation

5. The purpose of the ship simulator investigation was to determine the effects of deepening and widening the Brownsville navigation channel and to investigate the required size of the turning basin. Special attention was given to ensuring safe ship handling through the turn at Laguna Madre. Proposed improvements were evaluated by comparing runs made under existing conditions with those made under plan conditions.

6. The Brazos Island Harbor study reach was divided into four study areas for simulation. These test reaches were based on channel dimensions,

* Dennis W. Webb. 1990 (8 Jan). "Memorandum Report on Brazos Island Sensitivity Study," Memorandum for Record, CEWES-HR-N, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

type of ship traffic, and the navigation problem being addressed. The different study reaches as implemented on the US Army Engineer Waterways Experiment Station (WES) ship simulator are shown in Figure 2.

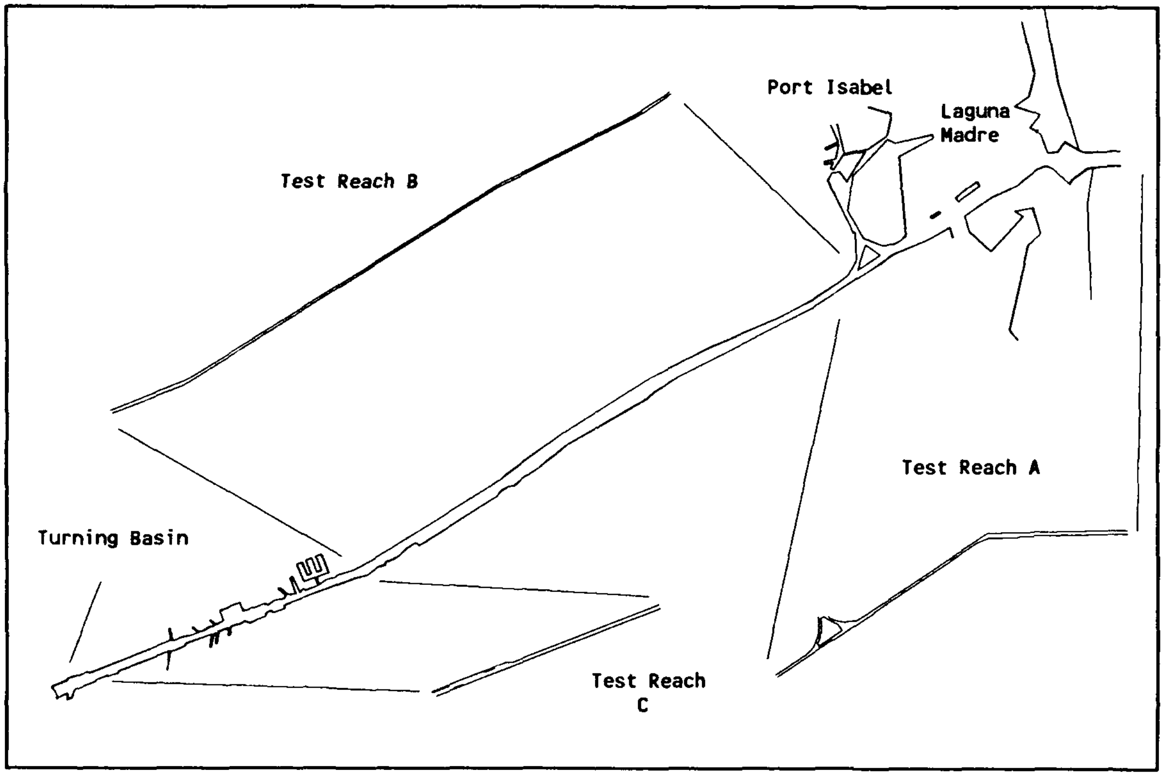

Figure 2. Simulated reaches

7. Test Reach A is defined as the Lower Brownsville Ship channel extending from the Gulf of Mexico through the entrance channel, the jetties, and Laguna Madre to a point just past the Port Isabel Channel. Four channel designs were tested in Test Reach A. In addition to the existing conditions and the Plan 1 improvements outlined in paragraph 3, Plan 2 consisted of deepening the existing channel to the proposed project depth, 42 ft, without any widening. Plan 3 (Figure 3) was the deepened channel with a bend widener in the turn at Laguna Madre and with the channel from there to the end of the test reach widened to 250 ft. The location and size of this widener were determined in the preliminary testing. One-way ship traffic was simulated in this reach.

8. Test Reach B is defined as the Central Brownsville Ship channel including the relatively straight reach of the 200-ft-wide channel between Port Isabel and Goose Island. Although data bases were prepared for this

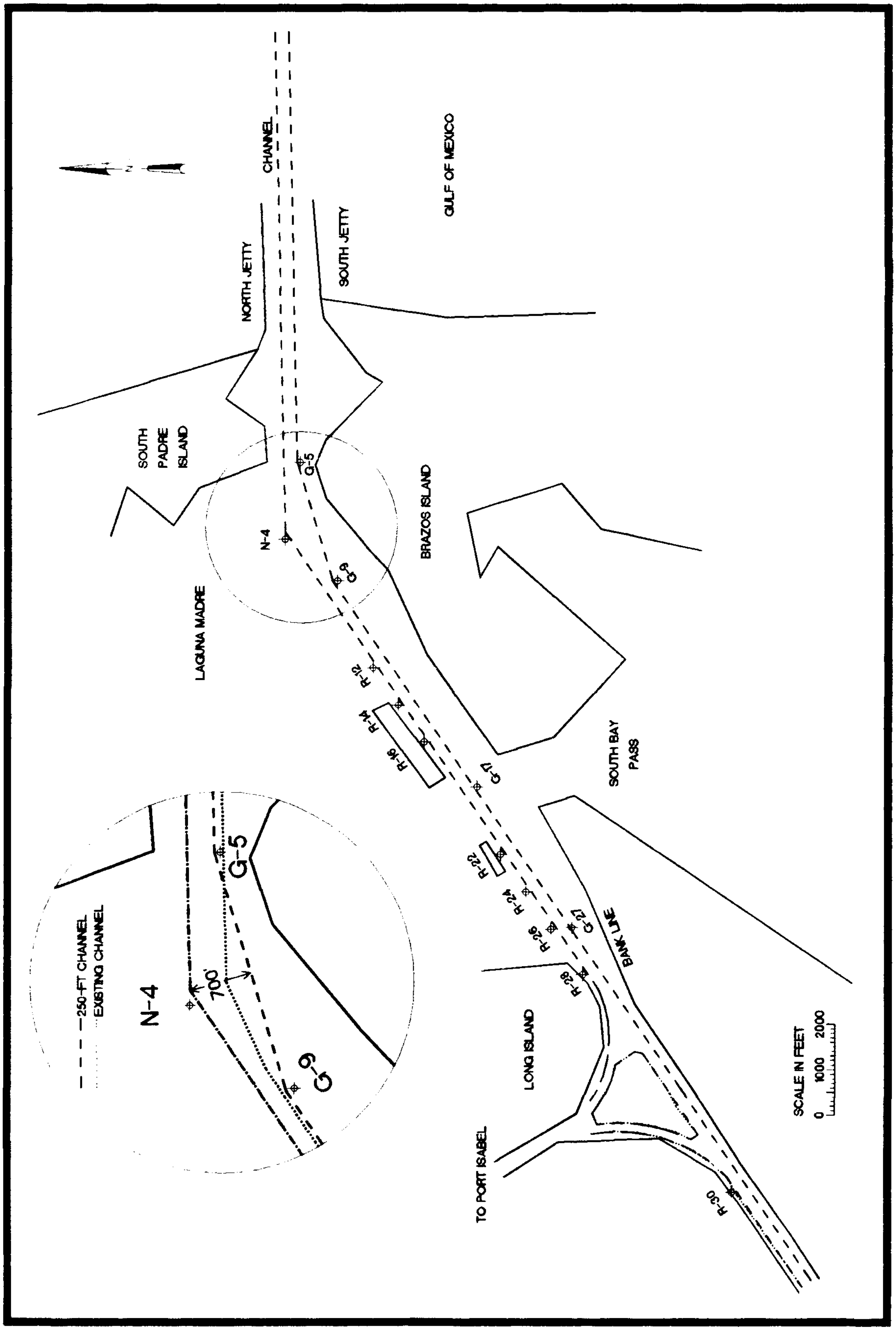

Figure 3. Test Reach A, Plan 3

entire reach, a reach of approximately 4 miles was chosen to represent Test Reach B. Based on conversations with the pilots, the reach from G-33 to G-37 was chosen. This reach includes a turn of approximately 5 degrees between G-33 and G-35 (Figure 4). Aids to navigation will be referred to as follows:

a. G-5 = green light No. 5

b. R-12 = red light No. 12

c. N-4 = nun buoy No. 4

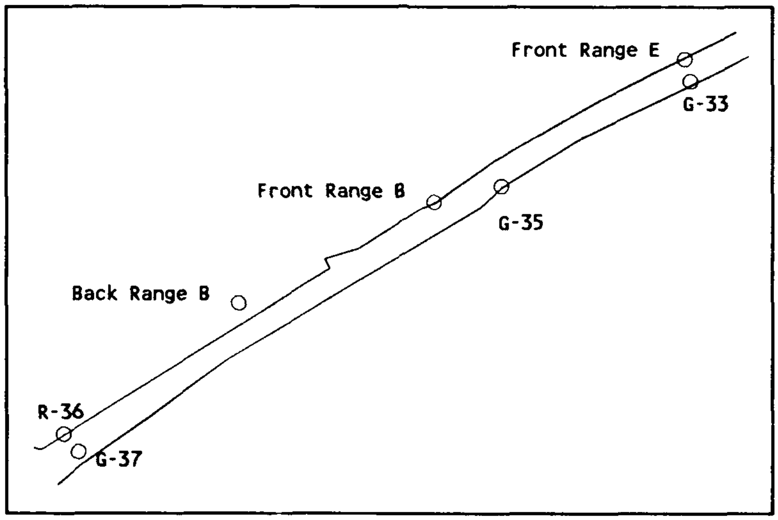

Figure 4. Test Reach B

9. Four channel designs were tested in Test Reach B. In addition to the existing conditions and the Plan 1 improvements outlined in paragraph 3, Plan 2 consisted of deepening the existing channel to the proposed project depths without any widening. Plan 3 was a 42-ft-deep, 200-ft-wide channel, with a 15-ft-deep side channel to serve tow traffic. The side channel was 100 ft wide and parallel to and on the south edge of the main navigation channel.

10. Two-way traffic tests for inbound runs were included to account for tow traffic, particularly empty tows leaving the Brazos Island Harbor. Based on conversations with the pilots, it was decided that the worst-case scenario was on an inbound transit, meeting and passing an outbound tow pushing four empty oil barges. The empty barges in strong wind are difficult to control and require a large angle in the channel. The towboat draft requires depths greater than 12 ft. In addition, the consequences of an accident are especially hazardous due to the explosive fumes in the empty barges. The tow

operated on a predetermined path, and passing occurred in a straight reach. The passing occurred port to port in a straight reach rather than in a bend because the pilots stated that they are in radio contact with the tows, and under no circumstances would passing occur in a bend.

11. Test Reach C is defined as the Upper Brownsville Ship channel from Goose Island to the turning basin. This reach contains many of the terminal facilities, and ships must proceed slowly through this area. The two channel designs tested were the existing conditions and the proposed improvements described in paragraph 3. One-way traffic was simulated in this reach.

12. The turning basin was tested separately from the test reaches. The existing and proposed turning basins were tested with tug assistance. Three different turning basins were tested in the real-time testing program: the existing condition, Plan 1 as described in paragraph 3, and Plan 2. Plan 2 had the same dimensions as Plan 1, but was deepened to 42 ft to accommodate turning loaded vessels.

PART II: DATA DEVELOPMENT

13. In order to simulate the study area, it is necessary to develop information relative to five types of input data:

a. Channel data base contains dimensions for the existing channel and the proposed channel modification. It includes the channel cross sections, slope angle, overbank depth, initial conditions, and autopilot track-line and speed definition.

b. Visual scene data base is composed of three-dimensional images of principal features of the simulated area, including the aids to navigation, docks, buildings.

c. Radar data base contains the features for the plan view of the study area.

d. Ship data file contains characteristics and hydrodynamic coefficients for the test vessels.

e. Current pattern data in the channel include the magnitude and direction of the current and the water depth for each cross section defined in the channel data base.

Channel

14. Channel cross sections are used to define the ship simulator channel data base. The information used to develop the channel data base came from the District-furnished hydrographic survey charts. This was the latest information available concerning depths, dimensions, and bank lines of the channel. State planar coordinates as shown on the annual survey were used for the definition of the data. Prototype survey ranges were used to locate the simulator cross sections. If the prototype survey ranges were not spaced close enough for simulator purposes, a new range was interpolated. In areas where the prototype survey ranges did not exist, data were obtained from navigation charts. Figure 5 illustrates the relationship of the simulator cross sections to the prototype survey ranges in Test Reach A. The arrows denote the location of prototype survey ranges. The prototype survey ranges in Test Reaches B and C corresponded to simulator cross sections.

15. The ship simulator model uses eight equally spaced points to define each cross section. At each of these points, a depth, current magnitude, and direction are required. For each cross section, the width, right and left bank slopes, and overbank depths are required. The channel depths at each of the eight points were provided by a TABS-2 model study (Hauck and Brown 1990)

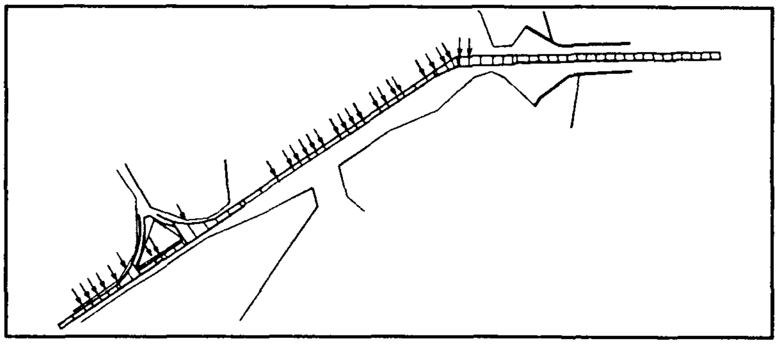

Figure 5. Test Reach A cross sections

conducted simultaneously with the development of the simulation data bases that computed the current magnitudes and directions.

16. The channel side slope and overbank depth are used to calculate bank force. The shallower the overbank and the steeper the side slope, the greater the computed bank force. A small difference (1 to 2 ft) in channel bottom and overbank depth produces negligible bank forces and moments.

17. A comparison between a typical simulator data base cross section and the corresponding prototype cross section is shown in Figure 6. These cross sections were taken at the Laguna Madre turn, with the solid line representing the prototype cross section at survey range 2000, or the fourth inland

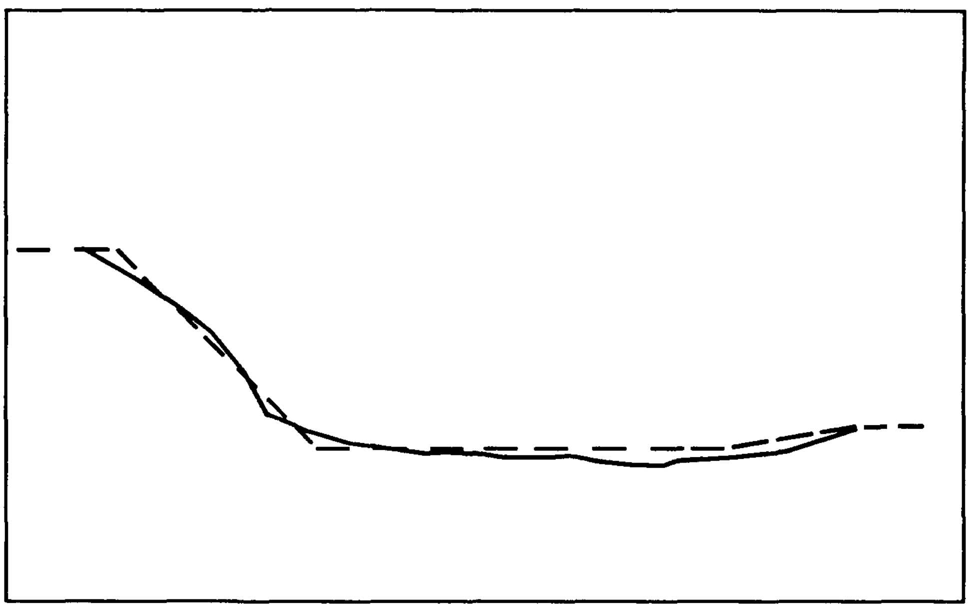

Figure 6. Cross-section comparison

cross section, and the dashed line representing the simulated cross section.

Visual Scene

18. The visual scene data base was created from the same maps and charts noted in the discussion of the channel. As in the development of the channel data base, the state planar coordinate system was used. Aerial and still photographs and pilot's comments obtained aboard a transiting ship during a reconnaissance trip to Brownsville constituted other sources of information for the scene. These allowed inclusion of the significant physical features and also helped determine which, if any, features the pilots use for informal ranges and location sightings. All aids to navigation such as buoys, channel markers, buildings, docks, docked vessels, towers, and tanks were included in the visual scene.

19. The visual scene is generated in three dimensions: north-south, east-west, and vertical elevation. As the ship progresses through the channel, the three-dimensional picture is constantly transformed into a two-dimensional perspective graphic image representing the relative size of the objects in the scene as a function of the vessel's position and orientation and the relative direction and position on the bridge for viewing. The graphics hardware used for the Brownsville project was a stand-alone computer (Silicon Graphics-Iris 2300) connected with the main computer to obtain information for updating the viewing position and orientation. This information includes parameters such as vessel heading, rate of turn, forward and lateral velocity, and position. Also, the viewing angle is passed to the graphics computer for the look-around feature on the simulator console, which encompasses only a 40-degree field of view. This feature simulates the pilot's ability to see any object with a turn of his head. The pilot's position on the bridge can also be changed from the center of the bridge to any position wing to wing to simulate the pilot walking across the bridge to obtain a better view, e.g., along the edge of the ship from the bridge wing.

Radar

20. The radar data base is used by the radar software to create a simulated radar for use by the test pilots. The radar data base contains

X- and Y-coordinates that define the border between land and water. The file also contains coordinates for any structure on the bank or extending into the water such as bridges and aids to navigation. In short, these data basically define what a pilot would see on a shipboard radar. The radar image is a continuously updated plan view of the vessel's position relative to the surrounding area. Three different ranges of 0.5 mile, 0.75 mile, and 1.5 miles were programmed to enable the pilot to choose the scale needed.

Current

21. A current data base contains current magnitude and direction at eight points across the channel at each of the cross sections defined in the channel. Channel bottom depths are also given at each of these eight points and are included in the channel definition. Interpolation of the data between cross sections provides continuous and smooth current patterns.

22. Accurate simulation of ship handling at the Laguna Madre turn required detailed modeling of the crosscurrents in that area. The tidal current was derived from the TABS-2 model study (Hauck and Brown 1990). Results from this hydrodynamic model were used to develop the current data bases for Test Reaches A and B. Because current velocities are negligible in Test Reach C and in the turning basin, no data bases were developed for these reaches.

Test Ship

23. Two deep-draft design ships and one tow were used for pilot testing. Each vessel required a ship data base consisting of the ship characteristics and coefficients used in the hydrodynamic program for calculating forces acting upon the vessel used in the testing program. In addition, the bow of the ship or tow would also be seen in the visual scene by the pilot from the ship bridge. Visual images of the ship bows for both design ships and the tow had been created for previous studies at WES.

24. The design ship used in the simulation of the existing channel was the *Asian Banner*, which is 610 ft long, has a 93-ft beam, and was loaded to a 32-ft draft with 4-ft underkeel clearance. A description of the ship model is included in Ankudinov (1988a).

25. The design ship for the proposed improvements was the *El Gaucho*.

The *El Gaucho* is of the Panamax class. This ship, a 775- by 106-ft bulk carrier, was loaded to 38 ft with 4-ft underkeel clearance for the transit tests. The model was modified to 32-ft draft with 4 ft of underkeel clearance for the proposed 36-ft turning basin. A description of the ship model is included in Ankudinov (1988b).

26. The design vessel for the tow tests was a towboat pushing four empty tank barges. The tow was two barges wide and two barges long. The barges were 250 ft long and 52 ft wide and drafted 2 ft when empty. The 1,400-hp towboat was 120 ft long with a beam of 40 ft and a draft of 9 ft. A description of the tow model is included in Ankudinov (1990).

Wind

27. Based on conversations with the local pilots, the dominant wind was determined to be 20 mph from the southeast. Winds of this direction and magnitude occur frequently. The simulator models winds as gusting plus or minus 70 percent about a 20-mph average. The direction of the wind also varies, with the southeast being the predominant direction.

Tugs

28. Turning basin tests were run with four 1,400-hp tugboats positioned at the pilot's command. Typically only two tugs are available for turning operations in the Brownsville Ship Channel. The tugs could be located at the port bow, starboard bow, port stern, and starboard stern. The tugs either pushed or pulled along a line normal to the vessel. The power applied by the tug was either none, one-fourth, one-half, three-fourths, or full. Because the simulator tugs do not occupy any physical space in the simulation, the pilots were instructed not to use tugs if they felt that the vessel was in an area too confined to allow a tug alongside.

PART III: NAVIGATION STUDY

29. Formal pilot testing was conducted with the only two professional pilots licensed for the Brownsville Ship Channel. Involving local professional pilots incorporated their experience and familiarity with handling ships in the study area in the project navigation evaluation. The tests were conducted at the Port of Brownsville on the WES portable ship simulator.

30. The portable simulator functions like the main WES simulator. In this study, the helmsman controls were manned by a WES engineer who responded to pilot commands during testing. The view out the window was provided by a 24-in. color monitor, rather than a picture projected on a screen.

Validation

31. The simulation was validated over a 4-day period with the assistance of a pilot licensed for the Brazos Island Harbor. The following information was verified and fine tuned during validation:

- a. The channel definition.
  - (1) Bank conditions.
  - (2) Currents.
- b. Wind forces.
- c. The visual scene and radar image of the study area.
  - (1) Location of all aids to navigation.
  - (2) Location and orientation of the bridges.
  - (3) Location and orientation of the docks.
  - (4) Location of buildings visible from the vessel.

Both design vessel models had been validated and used in previous simulations at WES.

32. To validate the reaction of the vessel to bank forces, several simulation runs were made with the vessel transiting the entire study area. Special attention was given by the pilot to the response of the ship to the bank forces. Problem areas were isolated, and the prototype data for these areas were examined. The values for the overbank depth, the side slope, or the bank force coefficient were then adjusted. Simulation runs were then undertaken through the problem areas, and if necessary, further adjustment was made. This process was repeated until the pilot was satisfied that the

simulated vessel response to the bank force was similar to that of an actual vessel passing through the same reach in the prototype.

33. The reaction of the vessel to current forces was verified by conducting several simulation runs over the entire study area. The pilot was instructed to pay attention to the current effects. The pilot was satisfied that the vessel response to the currents was similar to responses he had experienced in real life.

34. The visual scene and radar image of the study area were checked during validation of the other parameters. If the pilot noticed something missing or misplaced, this was checked against prototype information and corrected.

Test Conditions

35. Based on the preliminary tests, it was decided that the test schedule for Test Reach A should consist of inbound runs with both ebb and flood tides and outbound runs with flood tide only. The flood tide runs had a southeast wind of 20 mph acting upon the vessel. The ebb tide runs did not have a wind because analysis of the hydrodynamic model results indicated that the southeast wind held the water in the Laguna Madre, thereby reducing the crosscurrent velocity. Tests in Reaches B and C were conducted with "fair tide"; that is, the vessels were transiting in the same direction as the current. This is traditionally regarded as the more difficult condition to navigate. All tests in Reaches B and C and the turning basin were conducted with the 20-mph wind blowing from the southeast.

36. The Brazos Island Harbor testing schedule as implemented on the WES ship simulator is summarized in the following tabulation:

Test Reach	Direction	Tide	Wind	Traffic
A	Inbound	Flood	With	One way
	Inbound	Ebb	Without	One way
	Outbound	Flood	With	One way
B	Inbound	Flood	With	Two way
	Outbound	Ebb	With	One way
C	Inbound	Flood	With	One way
	Outbound	Ebb	With	One way
Turning Basin	--	None	With	--

37. Tests were conducted in a random order. The test condition (Test Reach A, B, C, or turning basin; inbound or outbound; existing or plan) was chosen at random. The chosen condition was then tested and removed from the list of conditions. This was done to prevent prejudicing the results as would happen if, for example, all existing conditions were run prior to running the plans. The skill gained at operating the simulator could show the plans to be easier than they really were.

38. During each run, the characteristic parameters of the ship were automatically recorded every 5 seconds. These parameters included the position of the ship's center of gravity, speed, revolutions per minute (rpm) of the engine, heading, drift angle, rate of turn, rudder angle, and port and starboard clearances.

39. The simulator tests were evaluated based on pilot ratings, ship tracks, and statistical analysis of various ship control parameters recorded during testing. The following section will present these three methods of analysis.

PART IV: STUDY RESULTS

Final Questionnaire

40. After finishing all test runs, the pilots completed a final questionnaire to give their opinions on the project as well as on the simulation. Some of the comments made by the pilots on the project follow:

1. How will deepening the channel affect ship maneuverability and safety?

"Deepening alone would have limited benefits. Combined with widening up to 250′ seems to have a better effect on maneuverability."

"For the size vessels we <u>now</u> handle it would be safer. But you deepen the channel and we will have bigger and deeper ships. So, it would make it a little harder."

2. Is there any difference in the bank force between the existing and the 42′ channel?

"With 200′ width - no. With 250′ width - less effect."

"Yes, I feel a greater force."

3. Is there any difference in the effect of the current between the existing and the 42′ channel?

"No."

"I felt less effect on small ship and more on larger ship."

4. Do you feel that the channel can be safely deepened to 42′ within the limits of the existing 200′ wide channel, after the turn at Laguna Madre? If not, what width would you recommend?

"No. 250′-300′ - Normally vessels capable of deeper draft and longer length will have more beam."

"I feel a 42′ channel would do <u>no good</u> at 200′, but 300′ wide would allow larger vessels than we have now."

5. Do you feel that the widener in the turn at Laguna Madre aids in the safe navigation of this area?

"Yes."

"No, I feel the widener decreases the safety during periods of ebb tide."

6. Do you feel that the turning of a vessel up to 775′ long can be safely accomplished in a turning basin smaller that the 1200′ basin that was tested?

"With the same conditions as the test, no. However, it can be done safely and has been under different conditions."

"Yes."

Composite Ship Track Plots

41. A complete set of the composite ship track plots for the channel test conditions is presented in Plates 1-31.

Ship Track Plots, Test Reach A

42. Composite piloted ship track plots for the four channel conditions tested in Area A are presented in Plates 1-12. In order to show the track plots at a readable scale, enlarged views (expanded 1.5 times) of the turn at Laguna Madre and the turnoff to Port Isabel are provided for all runs.

Inbound runs, flood tide

43. Track plots of Test Reach A, inbound runs with flood tide, are shown in Plates 1-4. The greatest navigation hazard for an inbound run with flood tide is being pushed north into Laguna Madre near N-4 by the crosscurrents. The 20-mph wind from the southeast also forces the ship into the bay. Uneven bank forces at the Port Isabel turnoff also present a problem to navigation. Examination of the piloted ship track plot of the inbound test for existing conditions (Plate 1) reveals that one vessel left the channel by 10 ft on the starboard side just after N-4. After completing the turn, one vessel left the channel by 10 ft between G-9 and G-17. The inbound Plan 1 ship track plot of the flood tide (Plate 2) shows ships leaving the channel on the north side by 90 ft near N-4. The ships went out of the channel farther than in the existing condition because the larger, deeper drafted vessel turns more slowly and is more affected by the crosscurrents. After completing the turn, none of the vessels came close to the channel edge. Plate 3 presents the piloted ship track plot of the inbound test for Plan 2. Examination of this plot shows a ship completely out the channel at N-4. After the turn was completed, none of the ships actually left the channel, but they came very close to the channel edge on the port side at R-22 and on the starboard side at R-26 and between the turns to Port Isabel. The piloted ship track plot of the flood tide test for Plan 3 (Plate 4) shows that although the pilots were

able to start their turn earlier and to compensate for the crosscurrents, one ship still left the channel by 15 ft on the north side at G-9. After completing the turn, none of the ships left the channel for the remainder of the run.

Inbound runs, ebb tide

44. Track plots of Test Reach A, inbound runs with ebb tide, are shown in Plates 5-8. Acting opposite from flood tides, the ebb crosscurrents aid the vessel by pushing it around the turn at Laguna Madre. However, because of this assistance, the pilot must hold the vessel on the north side of the channel prior to the turn, and turn at precisely the correct position. Uneven bank forces at the Port Isabel turnoff also present a problem to navigation. Plate 5, a piloted ship track plot of the inbound test for existing conditions, shows that although the pilots came close to the port edge of the channel near G-5 and the starboard edge between N-4 and R-12, at no time did the vessels leave the authorized channel. Once the pilots recovered from the turn, near G-9, they were able to keep the vessels in the channel. Examination of the piloted ship track plot of the inbound test for Plan 1 (Plate 6) reveals one vessel leaving the channel by 50 ft between G-5 and G-9. However, neither pilot left the channel on his second run through the turn under the Plan 1 conditions. After completing the turn, all vessels had considerable clearance for the remainder of the test reach. Plate 7, the piloted ship track plot of the inbound test for Plan 2, shows one pilot losing control of his ship near South Padre Island. However, on his second run through the turn, he did not leave the channel. Both pilots came closer to the channel edge on the straight reach after the turn. One vessel went 20 ft out of the channel at the Port Isabel turnoff. The piloted ship track plots of the ebb tide test for Plan 3 (Plate 8) show that one ship left the channel by 20 ft on the north side across from G-5. He did not leave the channel on his second run. After completing the turn, one vessel left the channel by 70 ft near G-9. Neither pilot left the 250-ft channel for the remainder of the run.

Outbound runs, flood tide

45. Track plots of Test Reach A, outbound runs with flood tide, are shown in Plates 9-12. The greatest navigation hazard for an outbound run with flood tide is being pushed north by the wind and crosscurrents into Laguna Madre while making the turn. Uneven bank forces at the Port Isabel turnoff also present a problem to navigation. Examination of the piloted ship track plot of the outbound test for existing conditions (Plate 9) reveals that the

pilots were able to stay within the authorized channel from the beginning of the run to the turn at Laguna Madre. At the turn, both runs were pushed to the north side of the channel by the flood tide and 20-mph southeast wind. However, neither run actually left the authorized channel. The piloted ship track plot of the outbound test for Plan 1 (Plate 10) shows that neither ship came close to the channel edge until G-5 at the turn. Immediately after completing the turn, both vessels swung to the north side of the channel, with one vessel going 10 ft out of the channel. Both pilots regained control of their ship, bringing the ships close to the southern edge of the channel; however, neither went out of the channel. Plate 11, the piloted ship track plot of the outbound test for Plan 2, shows that the pilots were able to keep the ship in the authorized channel until the turn. At the turn, one pilot lost control of his ship as it went completely out the channel. The other pilot, who began his turn earlier, was able to complete the run without grounding, although he came close near marker G-5. The piloted ship track plot test for Plan 3 (Plate 12) reveals that the pilots were able to keep their vessels in the authorized channel for the entire run. One pilot did come near the south edge of the channel after G-5, but did not go out of the channel.

Ship Track Plots, Test Reach B

46. Composite piloted ship track plots for the channel conditions tested in Test Reach B are presented in Plates 13-20. In order to show the track plots at a readable scale, an expanded view of the bend between G-33 and G-35 is provided for both inbound and outbound runs. An expanded view of the passing area is provided for inbound runs only. The expanded views are double scale. A line is plotted between the piloted ship and the tow at the point their centers of gravity passed.

Inbound runs, flood tide

47. Track plots of Test Reach B, inbound runs with flood tide, are shown in Plates 13-16. Plate 13, the piloted ship track plot of the inbound test for existing conditions, shows that one pilot stayed on the south edge of the channel to make the turn, while the other used the north side. The closest they came to the channel edge was 25 ft on the starboard and 20 ft on the port. After completing the turn, both pilots followed nearly identical paths

for the remainder of the transit. The pilots maneuvered the ships to 30 ft of the starboard edge of the channel and allowed 40 ft of clearance to the four-barge tow. With the 20-mph southeast wind acting nearly perpendicular to the port side of the vessels, the ships stayed between the center of the channel and the north edge of the channel for the remainder of the run. The piloted ship track plot of the inbound test for Plan 1 (Plate 14) shows that one pilot came within 35 ft of the north edge of the channel at the turn, while the closest either pilot came to the southern edge was 110 ft. After completing the turn, the vessels stayed on the north-central side of the channel for the remainder of the transit. The pilots hardly had to move their ships to starboard when passing the tow. They maintained a starboard clearance of greater than 40 ft and allowed 70 ft of clearance to the four-barge tow. Examination of the piloted ship track plot of the inbound test for Plan 2 (Plate 15) reveals that ships left the channel by approximately 10 ft on both sides of the channel. After completing the turn, both pilots stayed on the northern channel edge for the remainder of the transit. The pilots maneuvered the ships to allow 30 ft of clearance to the four-barge tow, but came within 8 ft of the starboard channel edge. The piloted ship track plot of the inbound test for Plan 3 (Plate 16) shows both pilots coming within 15 ft of the starboard edge of the channel and 30 ft of the port edge. During both runs the pilots managed to stay farther away from the starboard edge of the channel than they did for Plan 2. This is because the 15-ft-deep ledge on the port side reduced the bank effects on that side of the vessel. The ships' tendency to go toward the side of least pressure somewhat countered the wind. With the tow staying entirely out of the main navigation channel, the ships did not have to maneuver much away from the channel center line to allow for safe passing. The ship and tow passed with 65 ft of clearance and the ships had 45 ft of starboard clearance.

Outbound runs, ebb tide

48. Track plots of Test Reach B, outbound runs with ebb tide, are shown in Plates 17-20. A piloted ship track plot of the outbound test for existing conditions (Plate 17) shows both pilots following nearly identical paths for the entire run. Both pilots stayed on the northern side of the channel center line. Both pilots used the bank forces to help them make the outbound turn, and came within 15 ft of the port channel edge. Examination of the piloted track plots of Plan 1 (Plate 18) reveals that, as with the existing condition

runs, both pilots followed nearly identical paths for the entire run and stayed on the northern side of the channel center line. Both pilots used the bank forces to help them make the outbound turn, and came no closer than 75 ft to the port channel edge and had at least 120 ft clearance to starboard. Examination of the piloted ship track plot of the outbound test for Plan 2 (Plate 19) reveals both pilots following nearly identical paths for the entire run. The runs went as far as 20 ft out of the channel on the port side at the turn. Nearly 80 ft of clearance was available on the starboard side at this point. Plate 20, the piloted track plots of Plan 3 outbound runs, shows that, as with all previous outbound runs in this reach, both pilots followed the same paths for the entire run. The runs were generally nearer the center of the channel because the lower bank force on the south side of the channel somewhat compensated for the wind blowing the ship to the north side of the channel. Both pilots used the bank forces to help them make the outbound turn, and came within 15 ft of the port channel edge and had 60 ft of clearance to starboard.

Tow track plots

49. Track plots of the tow tests conducted at the WES ship/tow simulator in Vicksburg, MS, with licensed tow pilots are shown in Plates 21-24. Tests were run for the same conditions (existing, Plans 1, 2, and 3) as the deep-draft tests. The predetermined path for the deep-draft vessel was based on the results of the real-time simulation for each plan. Although some of the tow plots appear to hit the ship, especially for Plans 2 and 3, none of the tows had any trouble staying clear of the ship. Differences in tow speed, and thus an earlier or later passing position, as well as the different pilot's response to the vessel, produce a wide composite track plot in the passing reach. Plotted individually, all runs would show adequate clearance.

Ship Track Plots, Test Reach C

50. Composite piloted ship track plots for the channel conditions tested in Test Reach C are presented in Plates 25-28. Test Reach C is the harbor area and is transited at speeds of 4 knots or less. Tests were conducted only for existing conditions and the proposed deepening discussed in paragraph 3, Plan 1. Examination of these plots reveals no areas of low clearance or other danger. The channel in this reach is from 400 to 500 ft

wide. Plan 1 calls for the authorized width to be narrowed to 325-400 ft. It should be noted that ships up to 500 ft long are currently being turned in this reach. If these ships must be turned in the basin, increased transit times and costs will be incurred. If these ships are loaded 36 ft or deeper, and must be turned loaded, the turning basin would have to be deepened.

Ship Track Plots, Turning Basin

51. The visual and radar scenes for the turning basin included large ships docked at the port. These ships encroached into the turning basin, but it is not uncommon for ships to be docked at these locations. In order to test an accurate "worst case" scenario, their inclusion was necessary.

52. Turning basin tests were begun with the vessel moving 1 knot ahead. Both pilots used the same starting point for turns in the existing basin. For turns tested in the 1,200-ft basins, the pilots asked for different starting locations in the channel. This is because the pilots used different techniques for turning the vessels. One turned the ship clockwise, using the fact that most ships (including these simulator design vessels) are right-hand screws and will turn to the right when the ship propeller is in reverse. The other pilot started his turn farther north, so that he could put the ship's bow into the cutout area in the south part of the basin. The fact that the runs started at slightly different locations is pilot preference only.

53. Composite piloted ship track plots for the three turning basins tested are presented in Plates 29-31. Track plots of the turns in the existing basin (Plate 29) show that the closest any vessel came to the edge of the channel was 40 ft and the ships came no closer than 70 ft to the docked vessel. The size of the basin required was estimated by drawing a circle with a diameter of 850 ft, which enclosed the turning portion of all the runs. The track plots of the turns in the Plan 1 basin (Plate 30) show that the closest any vessel came to the edge of the channel was 40 ft and the ships came no closer than 70 ft to the docked vessel. A circle of 1,000-ft diameter would enclose all of the runs. Examination of Plate 31, the track plots of the turns in the Plan 2 basin, reveals that the closest any vessel came to the edge of the channel was 35 ft and the ships came no closer than 45 ft to the docked vessel. A circle of 1,050-ft diameter would enclose all of the runs.

Statistical Analysis

54. During each run, the control, positioning, and orientation parameters of the ship were recorded every 5 seconds. These parameters included position, speed, rpm of the propeller, rudder angle, rate of turn, heading, drift angle, and port and starboard clearances. An additional parameter, the maneuvering factor, is calculated as the rpm multiplied by the rudder angle. All statistical parameters are plotted against distance along track. The distance along track is calculated by projecting the position of the ship center of gravity perpendicular to the center line of the channel and is measured from the beginning of the center line (Figure 7). For reference purposes, the positions of aids to navigation are identified.

55. For all parameters except clearance, the statistical analysis is presented as a mean of means within a sample channel section. A 500-ft channel section was used. This means that for each individual run, each parameter was averaged over 500 ft, and these means were averaged over all runs under a given condition, thus a mean of the means. The standard deviation of the means was calculated for each run, and these standard deviations were averaged over all runs under a given condition.

56. Statistical analysis of clearance is presented as a mean of the minimum during a sample channel section. This means that the minimum clearance for port and starboard is found for each channel section of each run. These minimums are then averaged over all runs for each test condition.

Statistical Analysis, Test Reach A

57. A plot of the center line for Test Reach A and the distance from the beginning of the center line are shown in Figure 7.

Mean minimum clearance

58. Inbound, flood tide. Examination of the port and starboard clearance plot (Plate 32) reveals that during tests conducted in all channels, the ships had adequate clearance from the Gulf of Mèxico through the jetties to the turn. While making the turn at Laguna Madre, the ships had significant negative clearance values on the starboard side from distance 11,000 to 12,000 for both Plans 1 and 2. The groundings occurred on the starboard side because the flood tide crosscurrents pushed the vessels to the right at the turn.

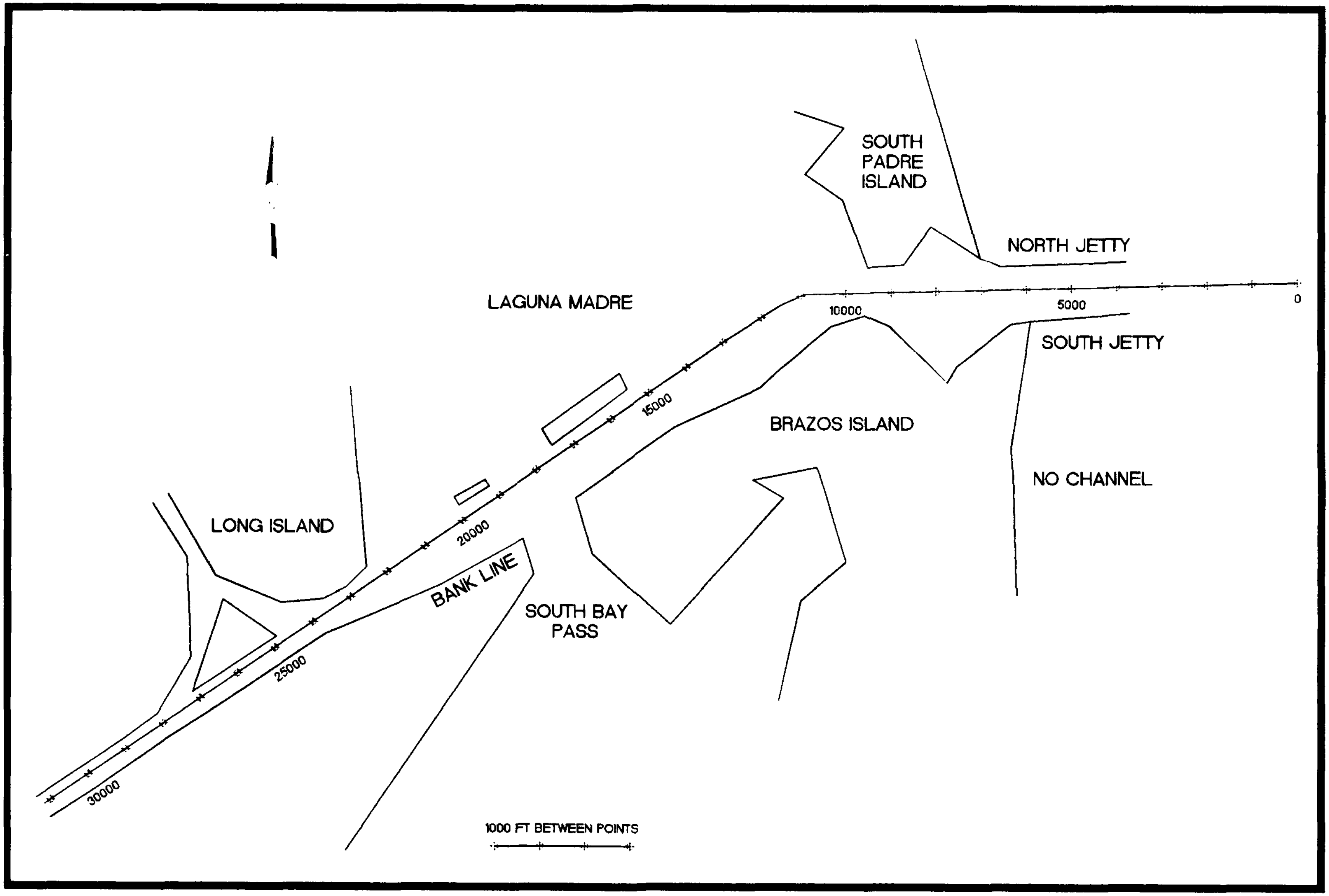

Figure 7. Distance along track, Test Area A

After making the turn, the ships had adequate clearance for the remainder of the test run for all of the plans excluding Plan 2. After making the turn, the ships on Plan 2 runs came within 10 ft of the channel edge several times.

59. Inbound, ebb tide. The plot of the average minimum port and starboard clearance versus distance along track (Plate 33) differed from those at flood tide mainly at the Laguna Madre turn. This is because the ebb tide crosscurrents, acting opposite those of a flood tide, pushed the ship to port. Plate 33 shows that Plan 2 had an average negative port clearance of nearly 75 ft at the Laguna Madre turn. Plan 1 had an average 0 port clearance at the turn. Prior to the turn, all of the plans except Plan 2 had adequate clearance. The clearances from completion of the turn to the turnoff to Port Isabel are greater for the inbound ebb runs than for the inbound flood runs because the ships were transiting against the ebb current. It is generally regarded as easier to pilot a vessel against the current. All runs except Plan 2 runs, which came within 10 ft of the channel edge at the turn to Port Isabel, had adequate clearance for the remainder of the run, after completing the turn at Laguna Madre.

60. Outbound, flood tide. Examination of the port and starboard clearance plot for outbound runs conducted with flood tide (Plate 34) shows that in the reach from R-30 to N-4, Plan 2 had the lowest average port clearance with 30 ft and the existing condition the lowest average starboard clearance with 20 ft. All channels had positive clearance at the Laguna Madre turn, except for Plan 2, which had an average port clearance of -70 ft.

Mean rudder angle

61. Inbound, flood tide. Plate 35, the plot of the mean rudder angle versus distance along track, shows that the existing conditions, Plan 1, and Plan 2 required considerable port rudder to make the turn. Both Plans 1 and 2 required more rudder than the existing conditions, while Plan 1 required more rudder than Plan 2. Plan 3 required half or less rudder than any other plan or existing conditions. All channels required starboard rudder to stop the turn to port. Plan 3 required the least rudder, while the existing condition and Plan 1 required more than Plan 2. Rudder was used for the remainder of the run to counteract the wind and the uneven bank forces at the turnoff to Port Isabel. All three plans for the 42-ft channel required more rudder than for the existing conditions at the turnoff to Port Isabel, due to the larger ship and more pronounced bank effects. However, the rudder used for the three

plans did not differ appreciably, once the turn had been completed.

62. Inbound, ebb tide. Plate 36, the plot of the mean rudder angle versus distance along track, shows that less port rudder was required to make the turn at Laguna Madre than for runs with flood tide. This is because the ebb currents assisted the vessel in making the turn, while the flood crosscurrents pushed the ship away from the turn. As with the flood tide runs, Plan 3 required half or less rudder than any other plan or existing conditions. The other area of increased rudder usage occurred at the turnoff to Port Isabel. Plan 2 required more rudder than did the other plans, but none used all the rudder that was available.

63. Outbound, flood tide. Plate 37, the plot of the mean rudder angle versus distance along track, shows that all plans required similar rudder at the Port Isabel turnoff, with the existing conditions requiring somewhat less. All plans used starboard rudder at Laguna Madre, with Plan 3 requiring the least amount of rudder, about one-half that for Plans 1 and 2. The existing conditions required more rudder than Plan 3, but less than Plans 1 and 2.

Mean engine rpm

64. The plots of mean engine rpm versus distance along track for all four channels tested in Area A (Plates 38-40) show that the pilots slowed the engine speed prior to the turn to increase the engine speed at the turn and thus improve the steerage during the turn for inbound runs. The engine speed was more consistent for Plan 3 than for any other plan during the inbound ebb tests. The outbound tests for all plans but Plan 3 showed that the ships required an increase in engine speed to make the turn but did not slow down prior to the turn, except for existing conditions.

Mean ship speed

65. The plots of mean ship speed versus distance along track for all three channels tested in Area A (Plates 41-43) show that the vessels slowed down prior to the turn at Laguna Madre in response to the lower engine rpm. The ships transiting inbound with the flood tide ran about 2 knots faster than the other conditions in which the vessel ran against the current.

Maneuvering factor

66. The maneuvering factor is calculated as the rpm multiplied by the rudder angle. The plots of the maneuvering factor versus distance along track for all three channels tested in Area A (Plates 44-46) show that Plan 3 required less than half of the maneuvering at the turn, when compared with the

other conditions. The existing conditions, with the smaller ship, required the least maneuvering in the straight section. The three plans required similar maneuvering in the straight reach.

Drift angle

67. Inbound, flood tide. The plot of drift angle versus distance along track (Plate 47) shows that at the turn, Plan 3 had about half the drift angle of the existing conditions, Plan 1, or Plan 2. The existing conditions had the least drift angle in the straight reach.

68. Inbound, ebb tide. The plot of drift angle versus distance along track (Plate 48) shows that at the turn, all plans had similar drift angles. However, all the runs had less drift angle than the inbound runs conducted with a flood tide. The existing conditions had the least drift angle in the straight reach.

69. Outbound, flood tide. The plot of drift angle versus distance along track (Plate 49) shows that at the turn, all plans had similar drift angles. As in the inbound runs, the existing conditions had the least drift angle in the straight reach.

Rate of turn

70. The plots of the rate of turn versus distance along track for all three channels tested in Area A are shown in Plates 50-52. The only major difference in these plots is for the inbound runs with flood tide. The plot for this condition shows that Plan 3 required less than half of the rate of turn at the Laguna Madre turn compared with the other conditions.

Statistical Analysis, Test Reach B

71. A plot of the center line for Test Reach B and the distance from the beginning of the center line are shown in Figure 8.

Mean minimum clearance

72. Inbound. Examination of the port and starboard clearance plot (Plate 53) reveals that Plan 1 had the most clearance for both port and starboard. Plan 1 had nearly 100 ft of port clearance for the entire run, while maintaining no less than 50 ft of starboard clearance. The lowest average clearance of any plan was the Plan 2 starboard clearance, which had an average clearance of 10 ft at the turn at distance 5,000 and at distance 11,000, where the ships passed the empty four-barge tow.

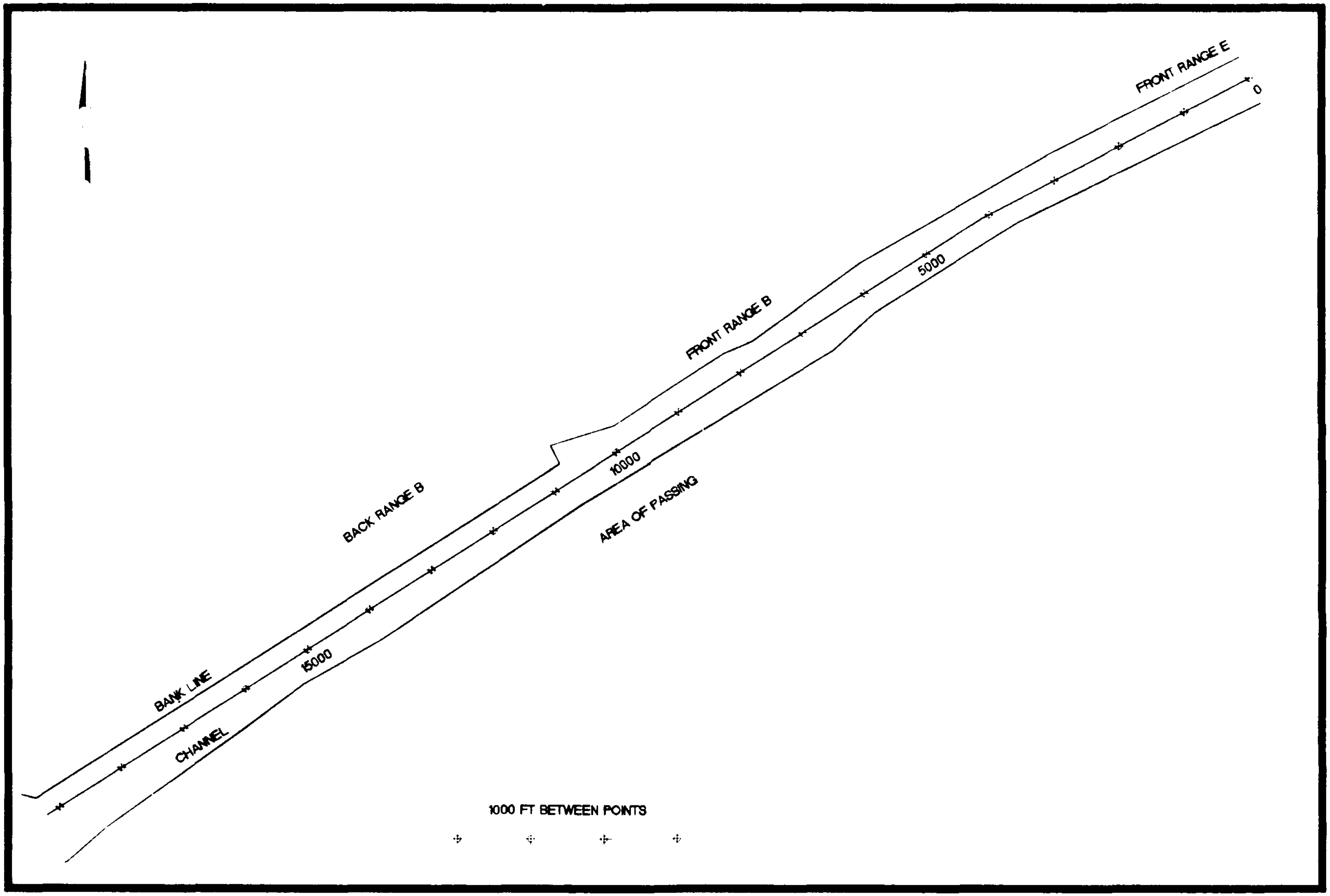

Figure 8. Distance along track, Test Area B

73. Outbound. Examination of the port and starboard clearance plot (Plate 54) reveals that Plan 1 had the most clearance for both port and starboard. Plan 1 had nearly 100 ft of starboard clearance for the entire run, while maintaining no less than 50 ft of port clearance. The lowest average clearance of any plan was the Plan 2 port clearance, which had a negative clearance at the turn, between 3,000 and 4,000 ft.

Mean rudder angle

74. Plate 55 shows the plot of the rudder angle versus distance along track for both inbound and outbound runs. This plot reveals that Plans 1 and 2 inbound required the most rudder for the passing situation between distances 8,000 and 11,000. None of the plans required hard rudder at any time during the run. The outbound runs required similar rudder throughout.

Mean engine rpm

75. The plot of the mean engine rpm versus distance along track for both inbound and outbound runs (Plate 56) reveals that Plans 1 and 2 inbound vessels slowed the most to meet the four-barge tow. The rpm of the outbound runs, which did not meet another vessel, did not change for any of the plans.

Mean ship speed

76. The plot of the mean ship speed versus distance along track for both inbound and outbound runs (Plate 57) shows the speed of the inbound vessels responding to the changes in rpm when meeting and passing the four-barge tow. The outbound runs showed little change in speed over the run. The speed of the smaller ship in the existing channel was less than the speed of the larger, more powerful ship in the proposed channels.

Maneuvering factor

77. The plots of the maneuvering factor versus distance along track for all channels tested in Area B, inbound and outbound (Plate 58), show little difference between the plans and the existing conditions.

Drift angle

78. The plots of the drift angle versus distance along track, inbound and outbound, are shown in Plate 59. These plots show little difference in the drift angle between the plans and the existing conditions.

Rate of turn

79. The plots of the rate of turn versus distance along track, inbound and outbound, are shown in Plate 60. These plots show little difference in the rate of turn between the plans and the existing conditions.

Statistical Analysis, Test Reach C

80. Plots of the center line for Test Reach C and the distance from the beginning of the center line are shown in Figure 9.

Mean minimum clearance

81. Examination of the port and starboard clearance plots for both inbound and outbound runs (Plate 61) reveals that none of the clearance values were less than 50 ft.

Mean rudder angle

82. Plate 62 shows the plot of the rudder angle versus distance along track for both inbound and outbound runs. This plot reveals that all conditions required similar rudder throughout the run and required less than 20 percent of the rudder available.

Mean engine rpm

83. The plots of the mean engine rpm versus distance along track for the inbound runs (Plate 62) show vessels for the existing condition slowing the engine as they neared the upper end of the port. Outbound ships slowed their engine speed for both existing and plan conditions as they neared the upper end of the port.

Mean ship speed

84. The plots of the mean ship speed versus distance along track for both inbound and outbound runs (Plate 63) show little difference in the speeds of the vessels.

Maneuvering factor

85. The plots of the maneuvering factor versus distance along track, inbound and outbound (Plate 63), show little difference between the plans and the existing conditions.

Drift angle

86. The plots of the drift angle versus distance along track, inbound and outbound, are shown in Plate 64. These plots show little difference in the drift angle between Plan 1 and the existing conditions.

Rate of turn

87. The plots of the rate of turn versus distance along track, inbound and outbound, are shown in Plate 64. These plots show little difference in the rate of turn between Plan 1 and the existing conditions.

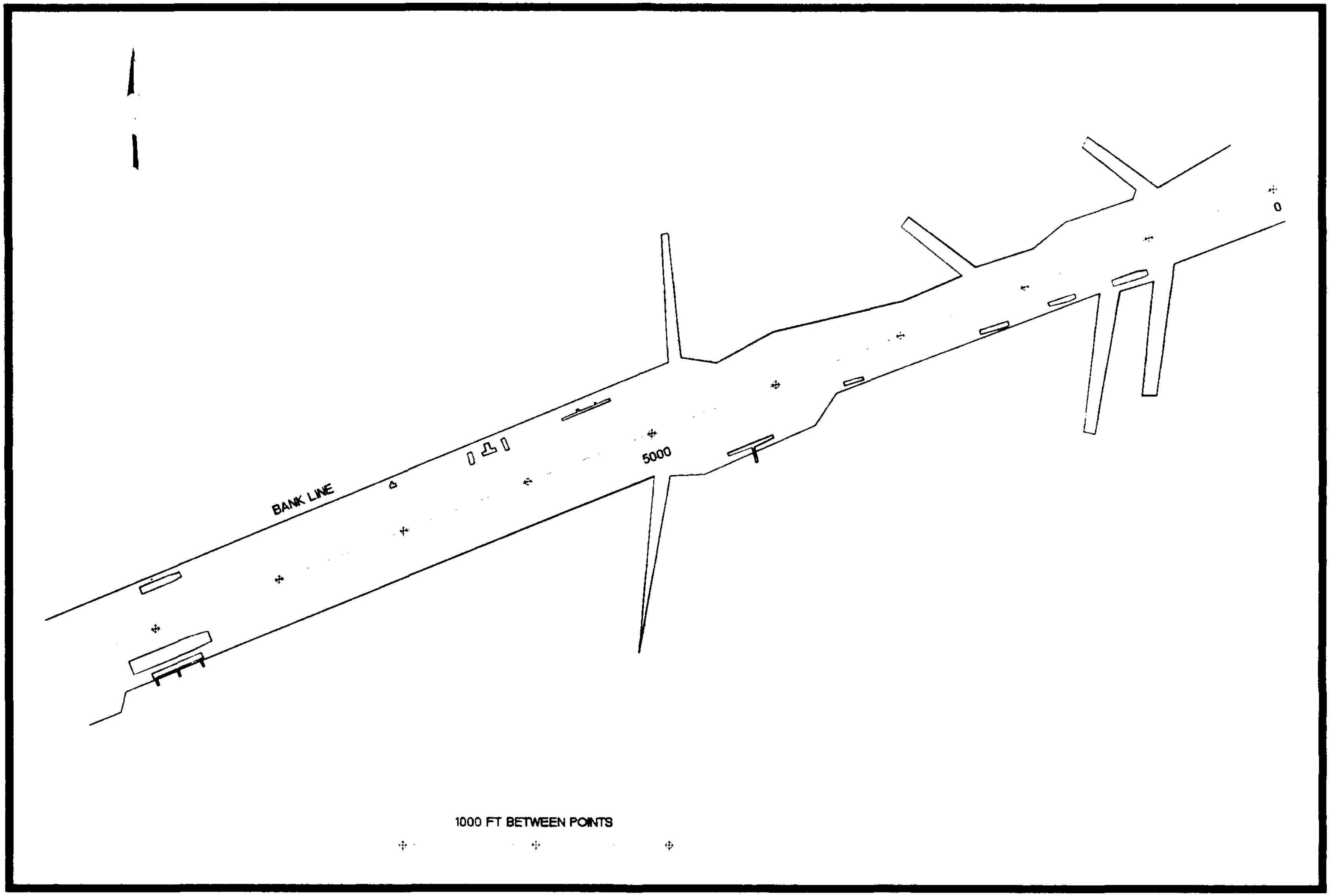

Figure 9. Distance along track, Test Area C

Part V: RECOMMENDATIONS

88. Based on the real-time pilot results, WES proposes the following channel layouts:

a. Test Reach A. Plan 3 is recommended with the following modifications (Figure 10):

   (1) The widener should be modified by moving the southern edge 100 ft farther north than was tested in Plan 3.

   (2) The northernmost point of the turn (near N-4) should be moved approximately 200 ft north. As a part of this recommendation, a light should be placed on N-4 for night transits.

   (3) The channel should be 300 ft wide at G-9, narrowing to 250 ft at R-14 and continuing at 250 ft to the end of the test reach (R-30).

   These modifications improve on Plan 3 by reducing the bank effects on both sides of the channel at the turn. This allows the pilots to take advantage of the widener, without experiencing additional problems due to the loss of pressure on the southern side of the ship. Widening the turn on the north corner also gives the ships additional room to swing their stern during the turn. This widening may be accomplished by the parallel banks method in EM 1110-2-1613 (US Army Corps of Engineers 1983). If a 300-ft-wide channel is authorized at the end of the turn, the pilots have a wider channel on inbound runs as they complete the turn, as well as having additional width to stop the ship from swinging after the turn. A channel width of 250 ft is recommended for the channel reach from R-14 to west of R-30. There are uneven bank effects in this reach, especially at the turnoff to Port Isabel, as well as stronger currents than in the more inland reach of the channel.

b. Test Reach B. An authorized channel width of 250 ft is recommended beginning at R-30. Considering the additional 50 ft and the 3V on 1H slope, this would provide tow traffic a width of 130 ft with water at least 15 ft deep.

c. Test Reach C. The proposed channel, Plan 1, is recommended for this reach.

d. Turning basin. The proposed basin, Plan 1, is recommended and is adequate for turning ships drafting 32 ft. The Plan 2 turning basin is adequate for drafts up to 38 ft.

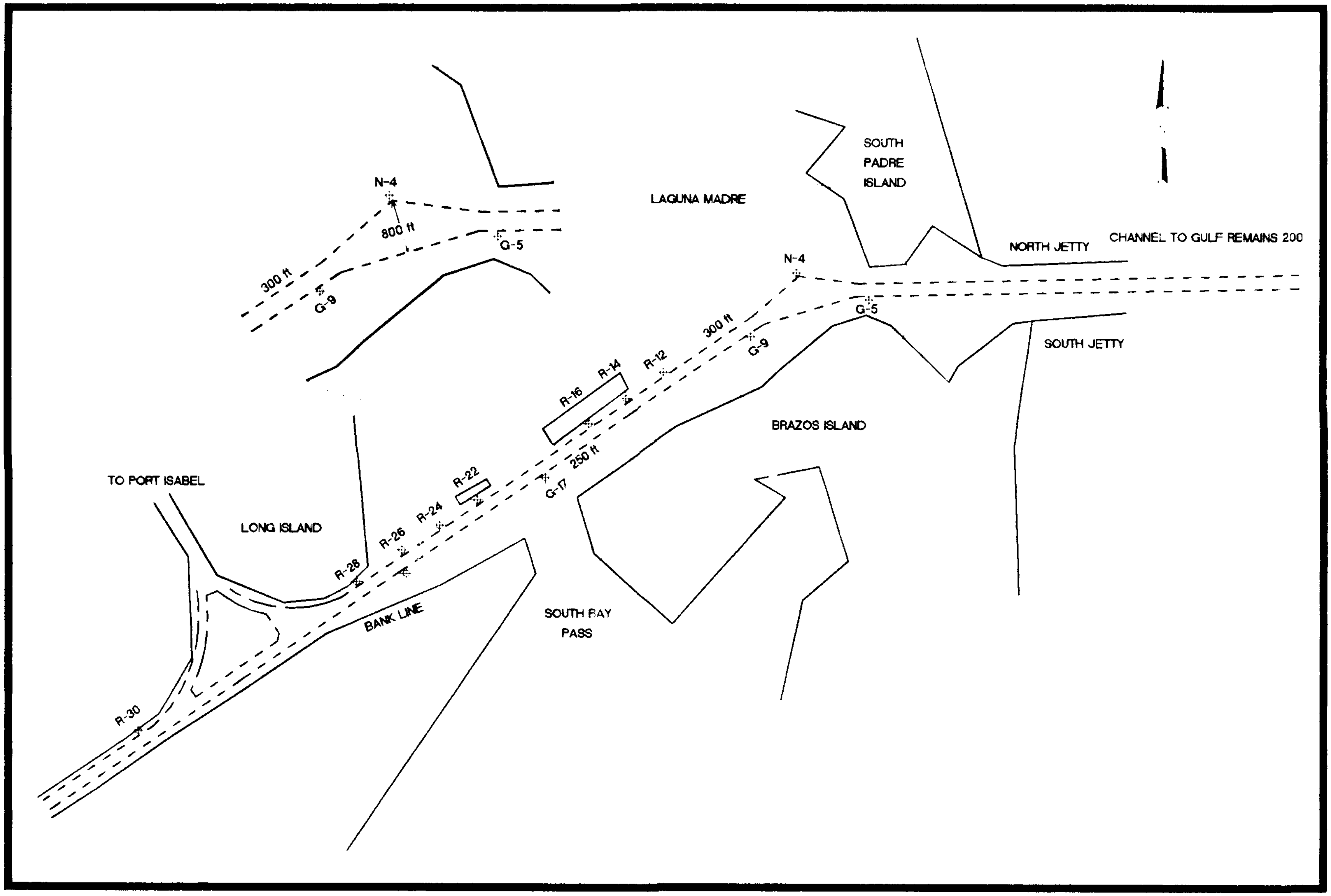

Figure 10. Recommended channel, Test Area A

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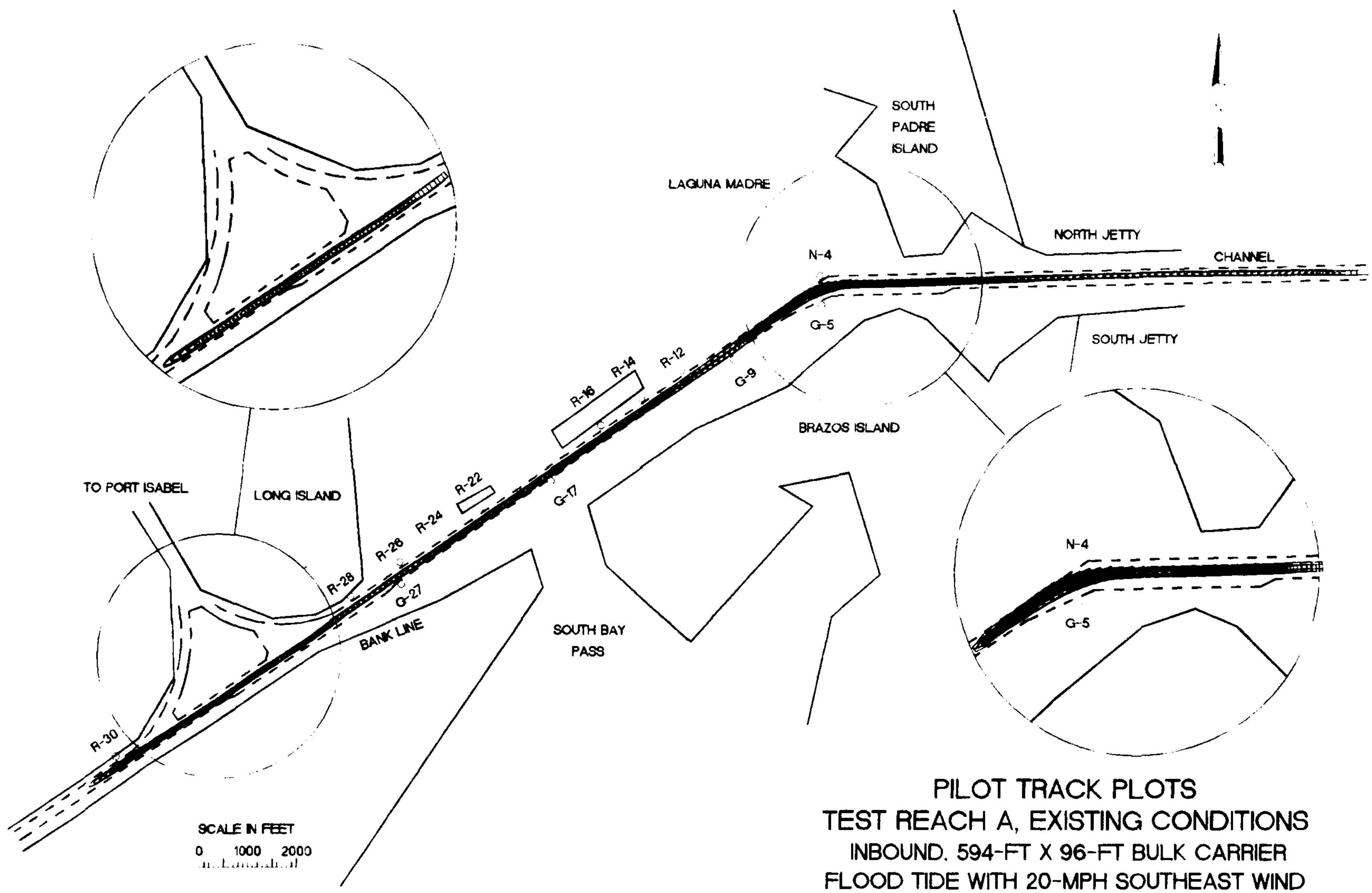
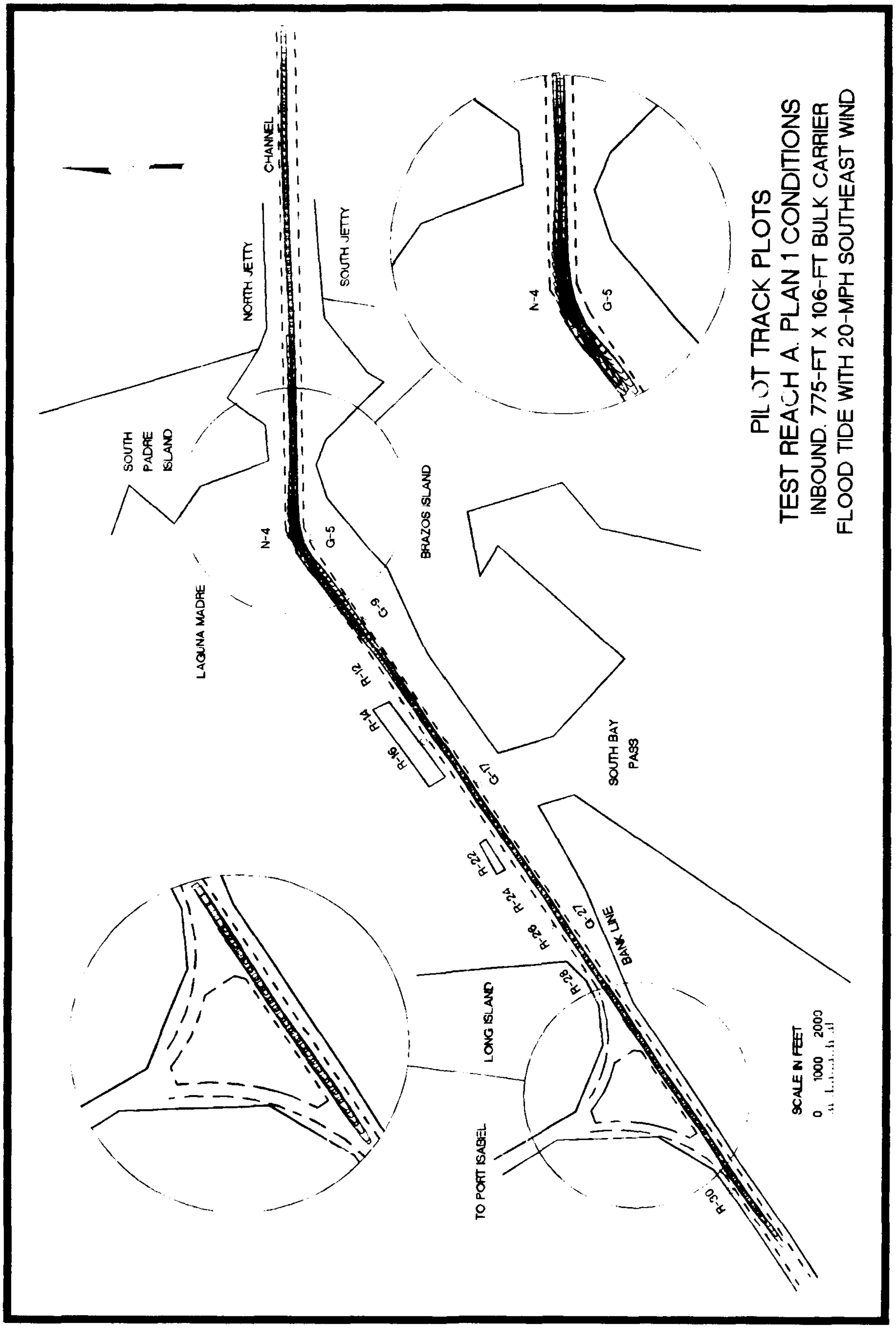
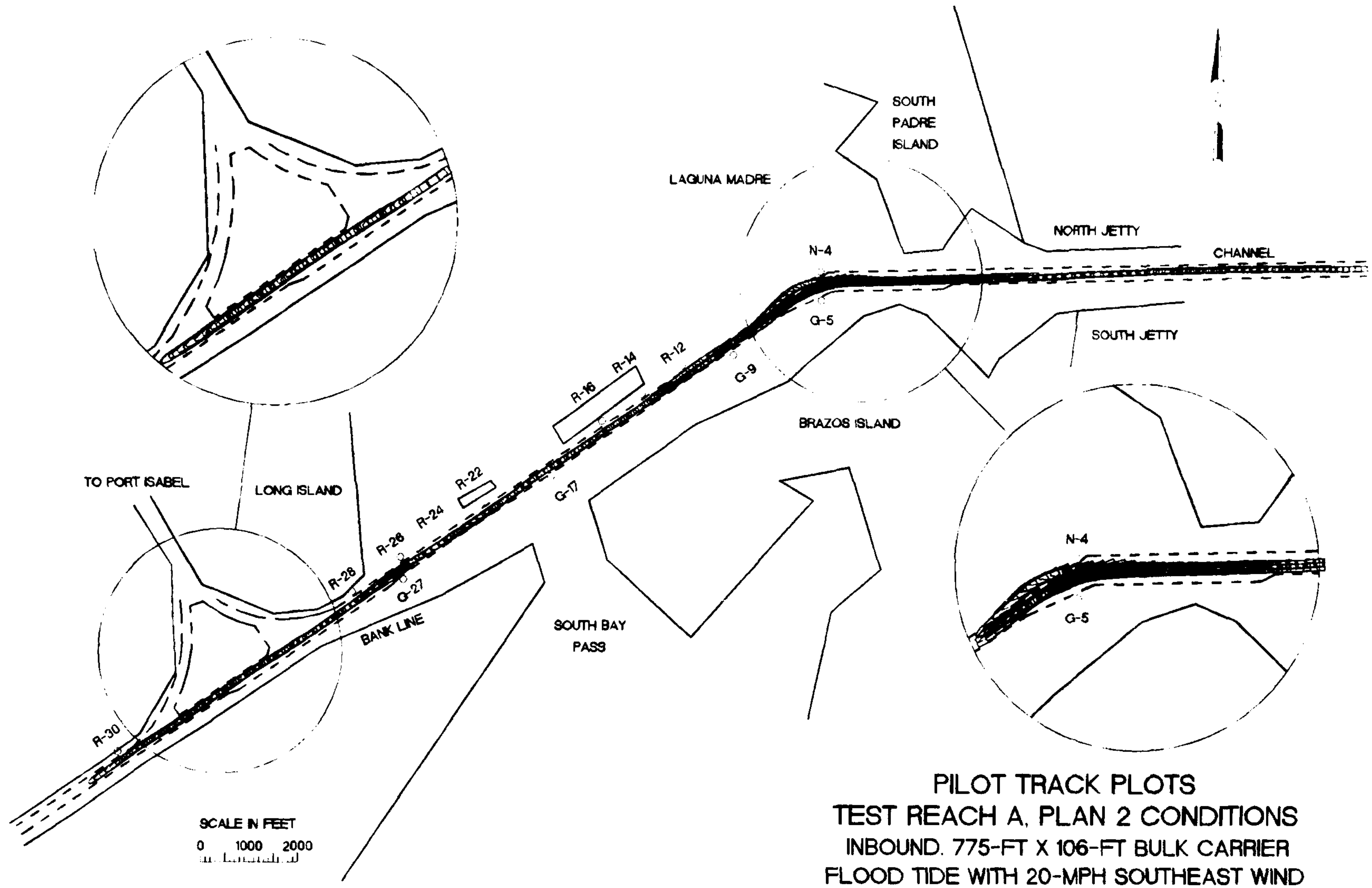


PILOT TRACK PLOTS
TEST REACH A, EXISTING CONDITIONS
INBOUND, 594-FT X 96-FT BULK CARRIER
FLOOD TIDE WITH 20-MPH SOUTHEAST WIND

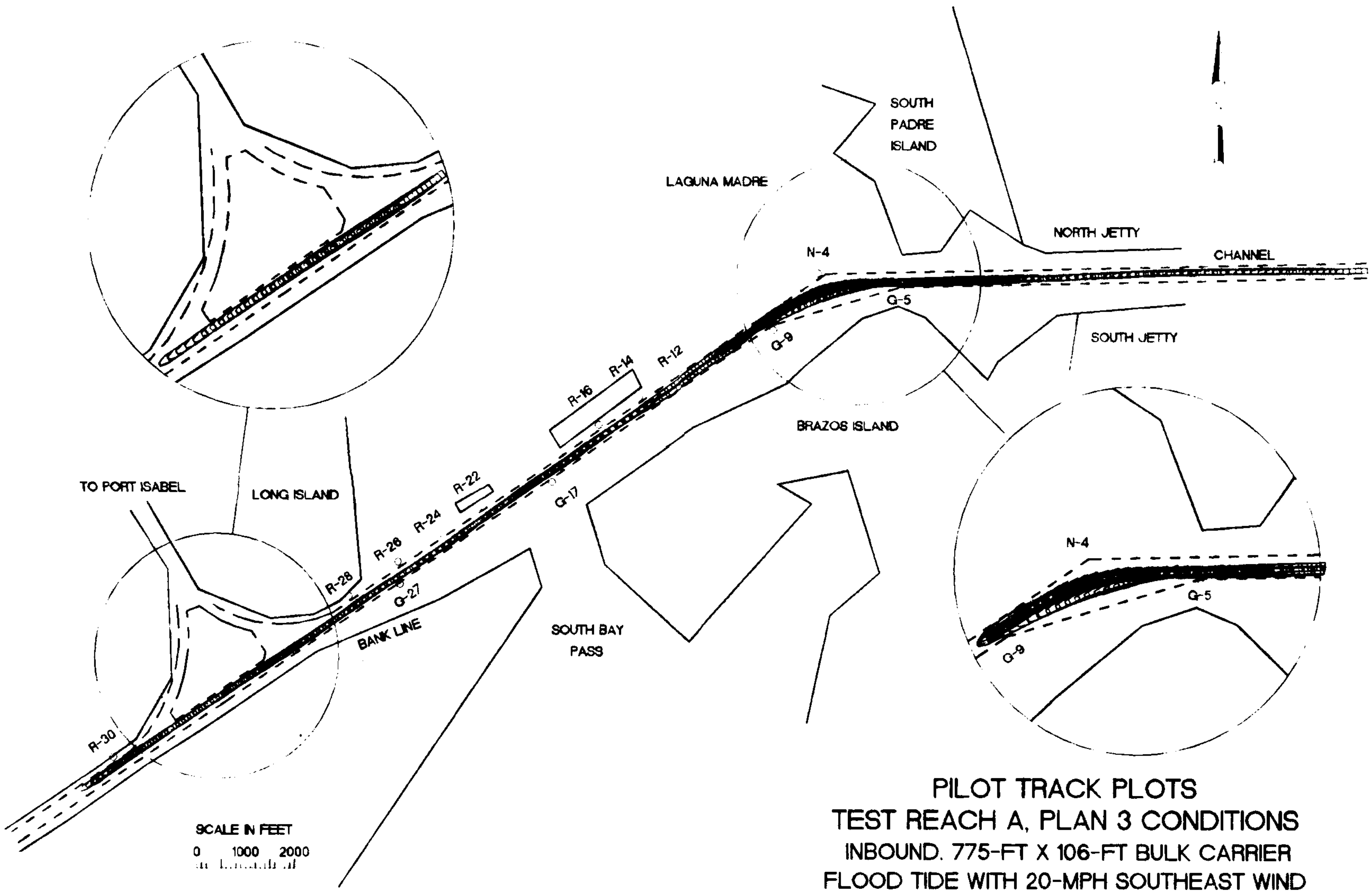


PILOT TRACK PLOTS
TEST REACH A. PLAN 1 CONDITIONS
INBOUND. 775-FT X 106-FT BULK CARRIER
FLOOD TIDE WITH 20-MPH SOUTHEAST WIND

PLATE 2

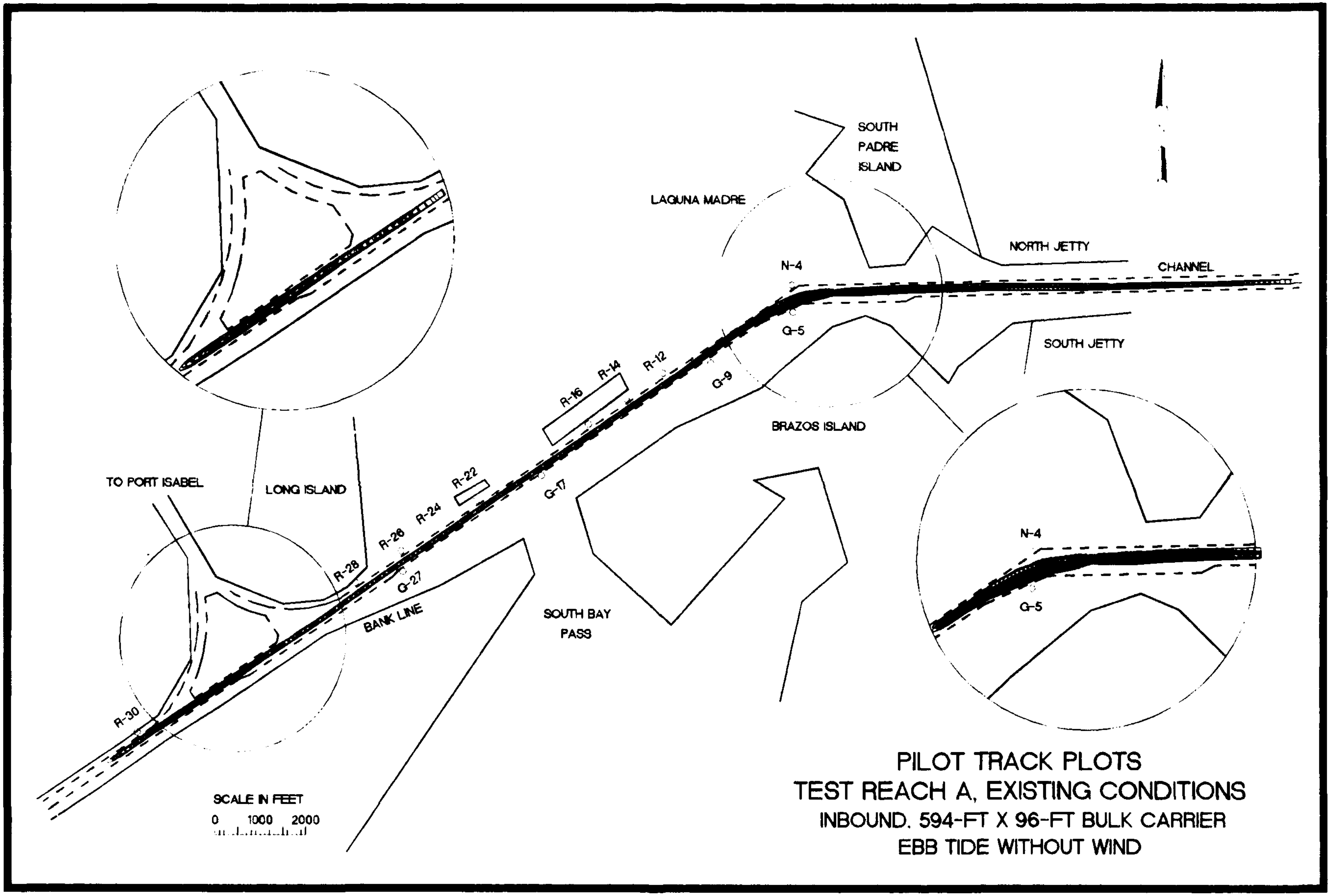


PILOT TRACK PLOTS
TEST REACH A, PLAN 2 CONDITIONS
INBOUND. 775-FT X 106-FT BULK CARRIER
FLOOD TIDE WITH 20-MPH SOUTHEAST WIND

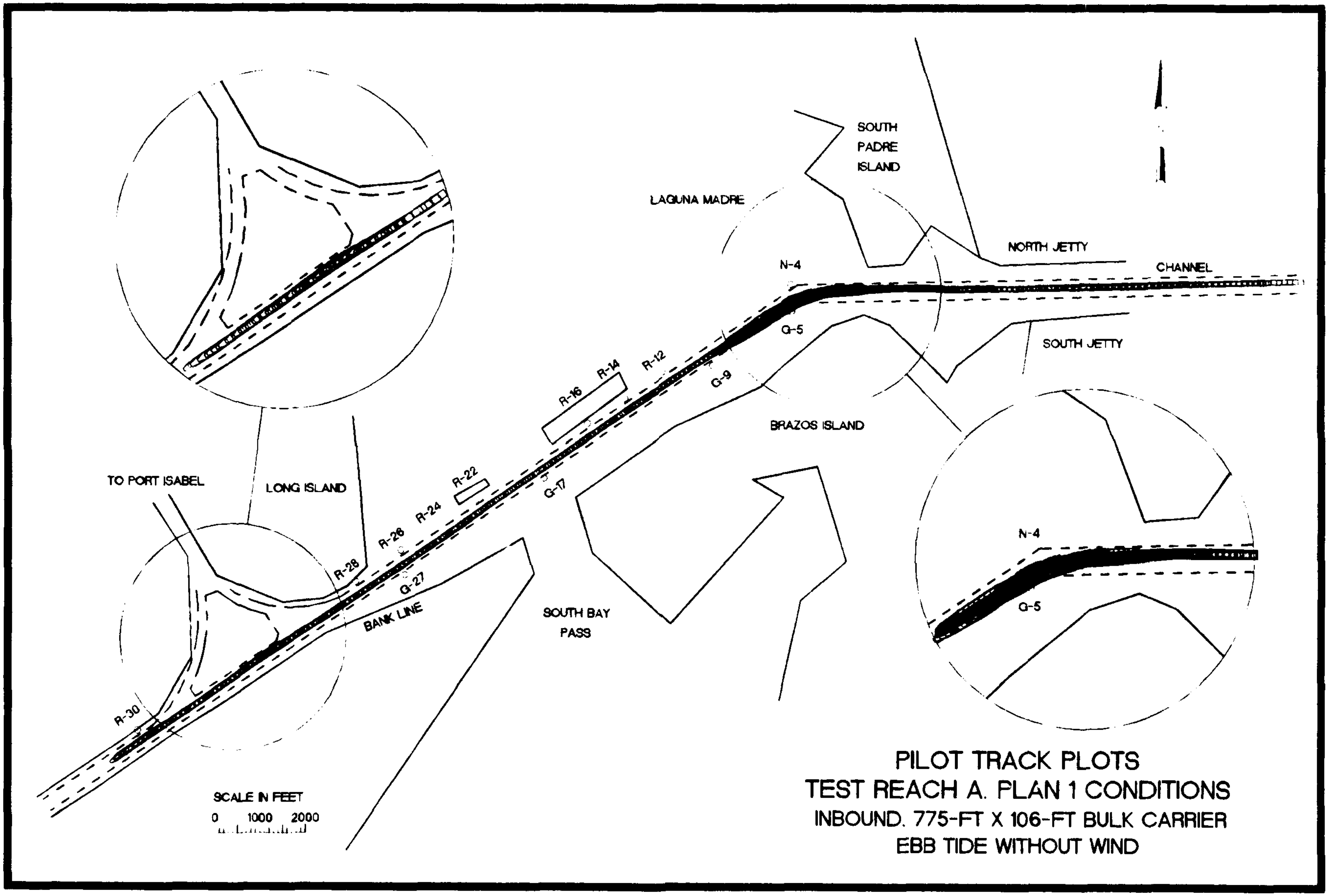


PILOT TRACK PLOTS
TEST REACH A, PLAN 3 CONDITIONS
INBOUND. 775-FT X 106-FT BULK CARRIER
FLOOD TIDE WITH 20-MPH SOUTHEAST WIND

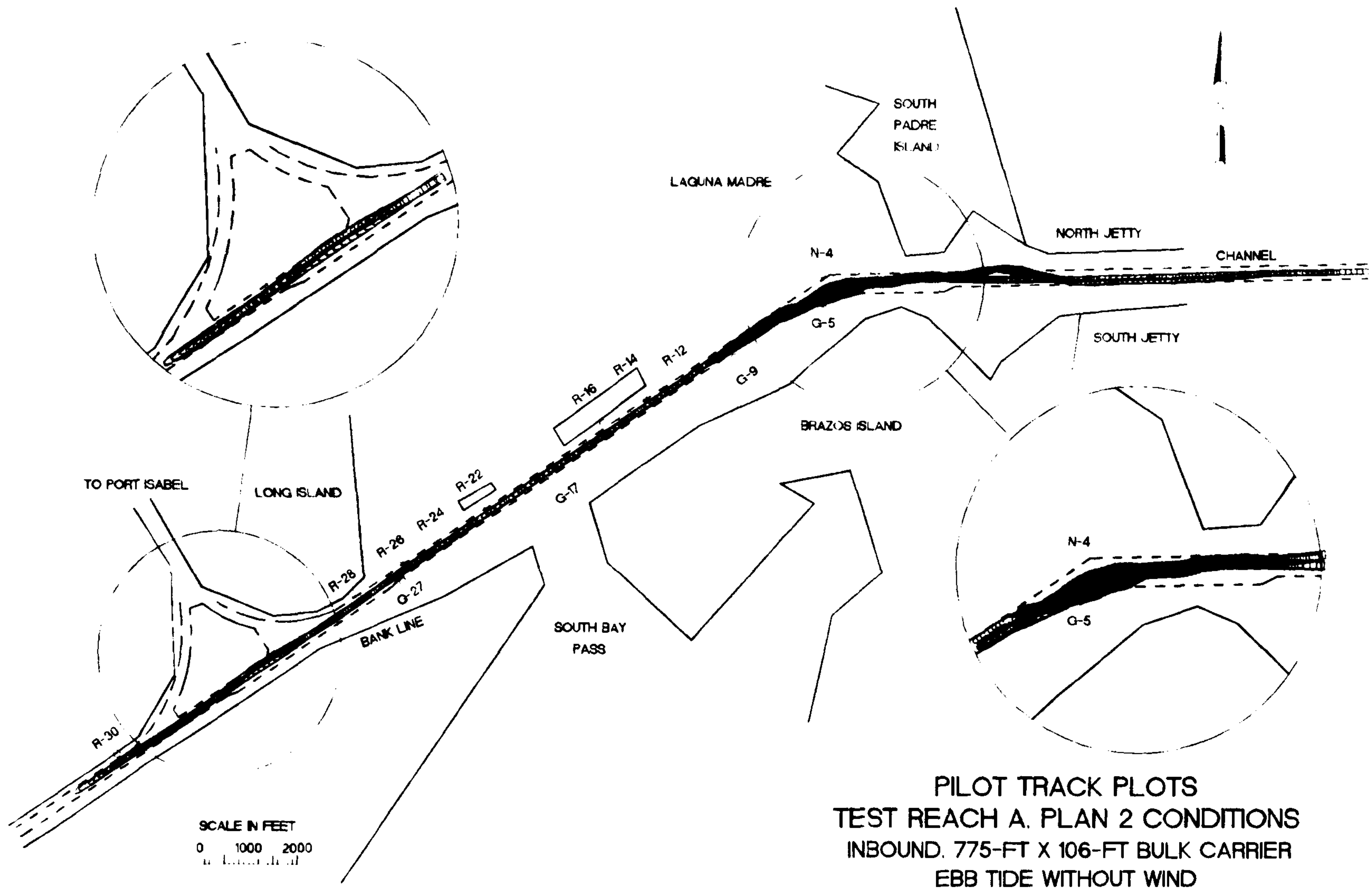
PLATE 4



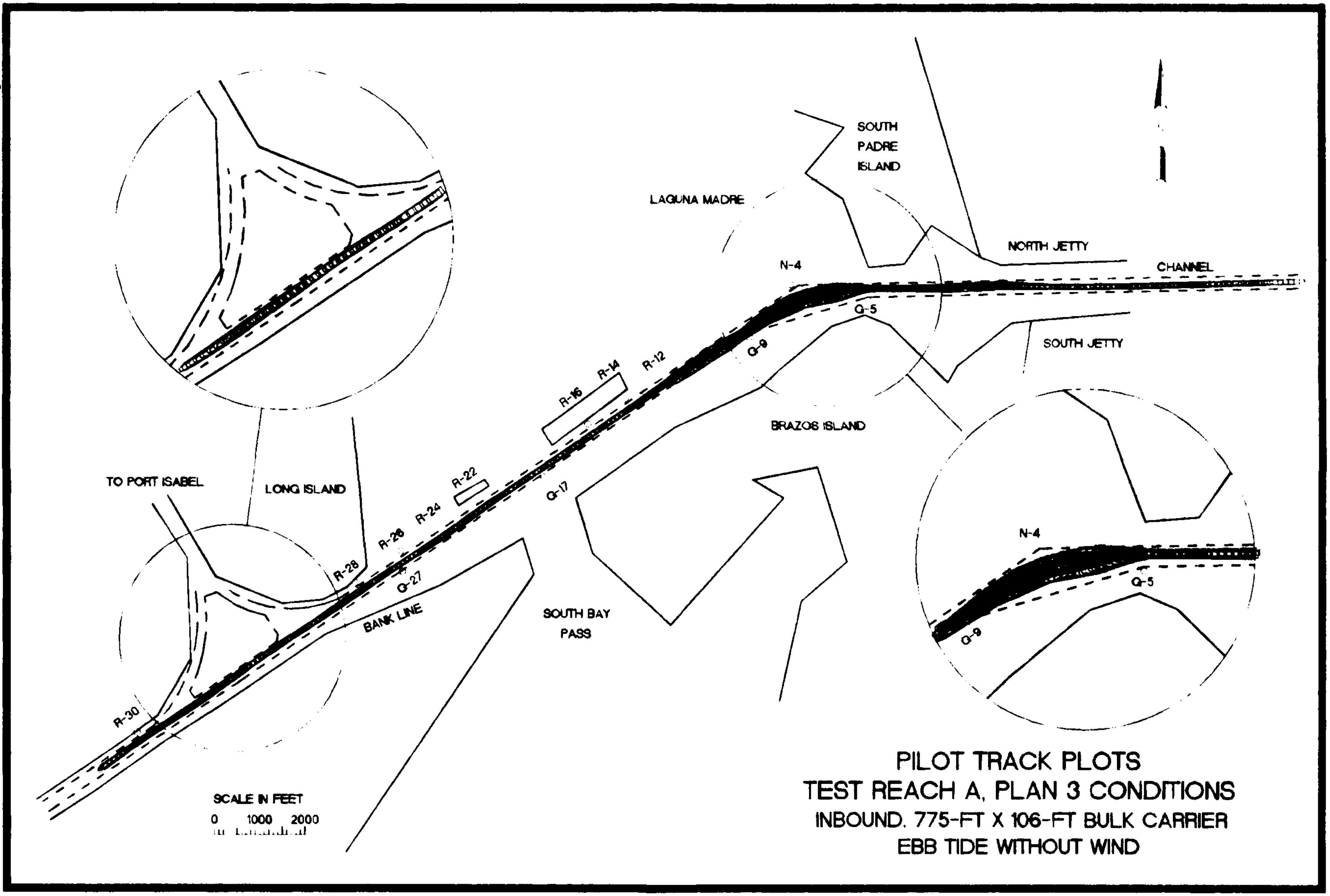
PILOT TRACK PLOTS
TEST REACH A, EXISTING CONDITIONS
INBOUND. 594-FT X 96-FT BULK CARRIER
EBB TIDE WITHOUT WIND



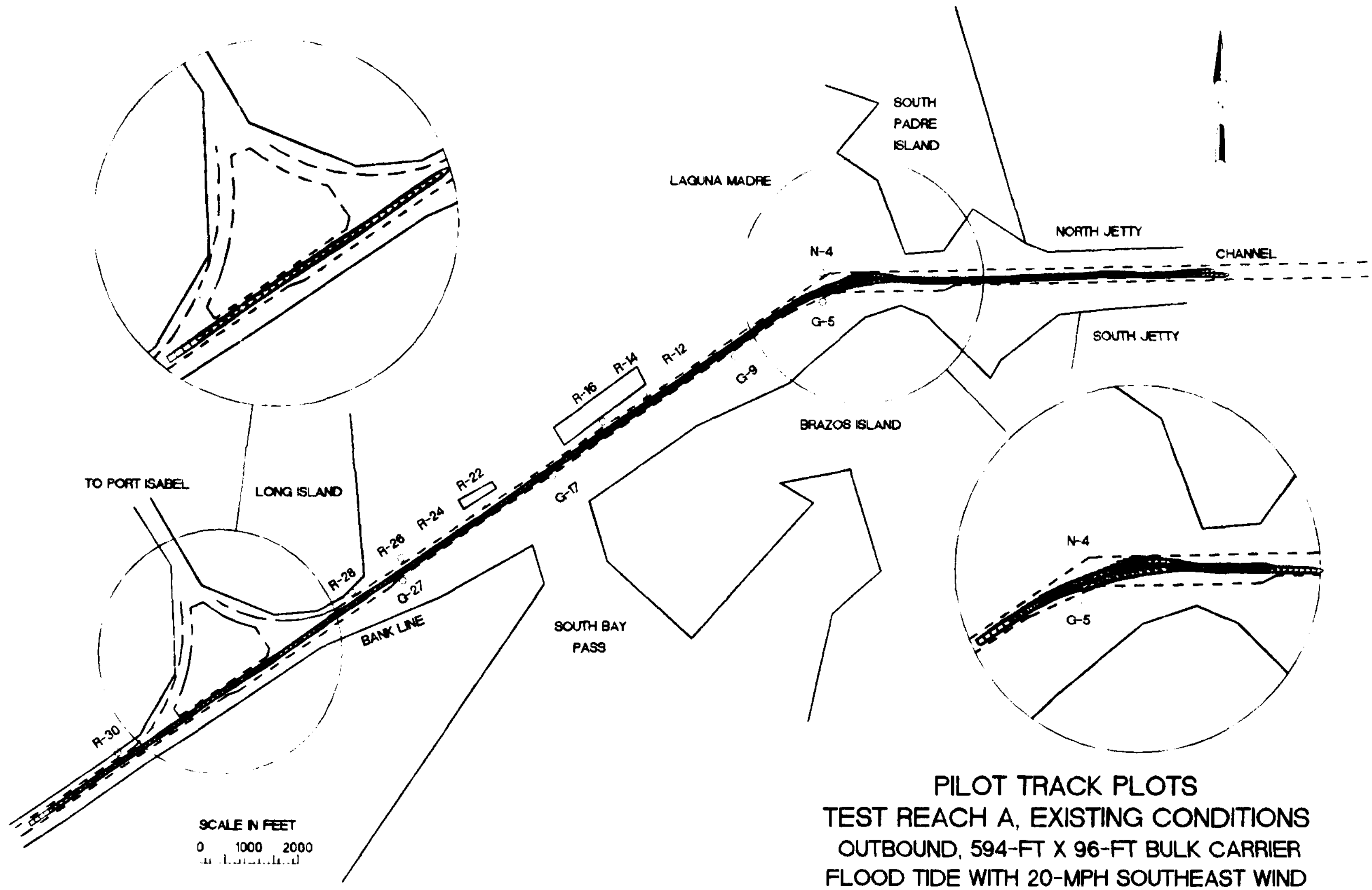
PILOT TRACK PLOTS
TEST REACH A. PLAN 1 CONDITIONS
INBOUND. 775-FT X 106-FT BULK CARRIER
EBB TIDE WITHOUT WIND



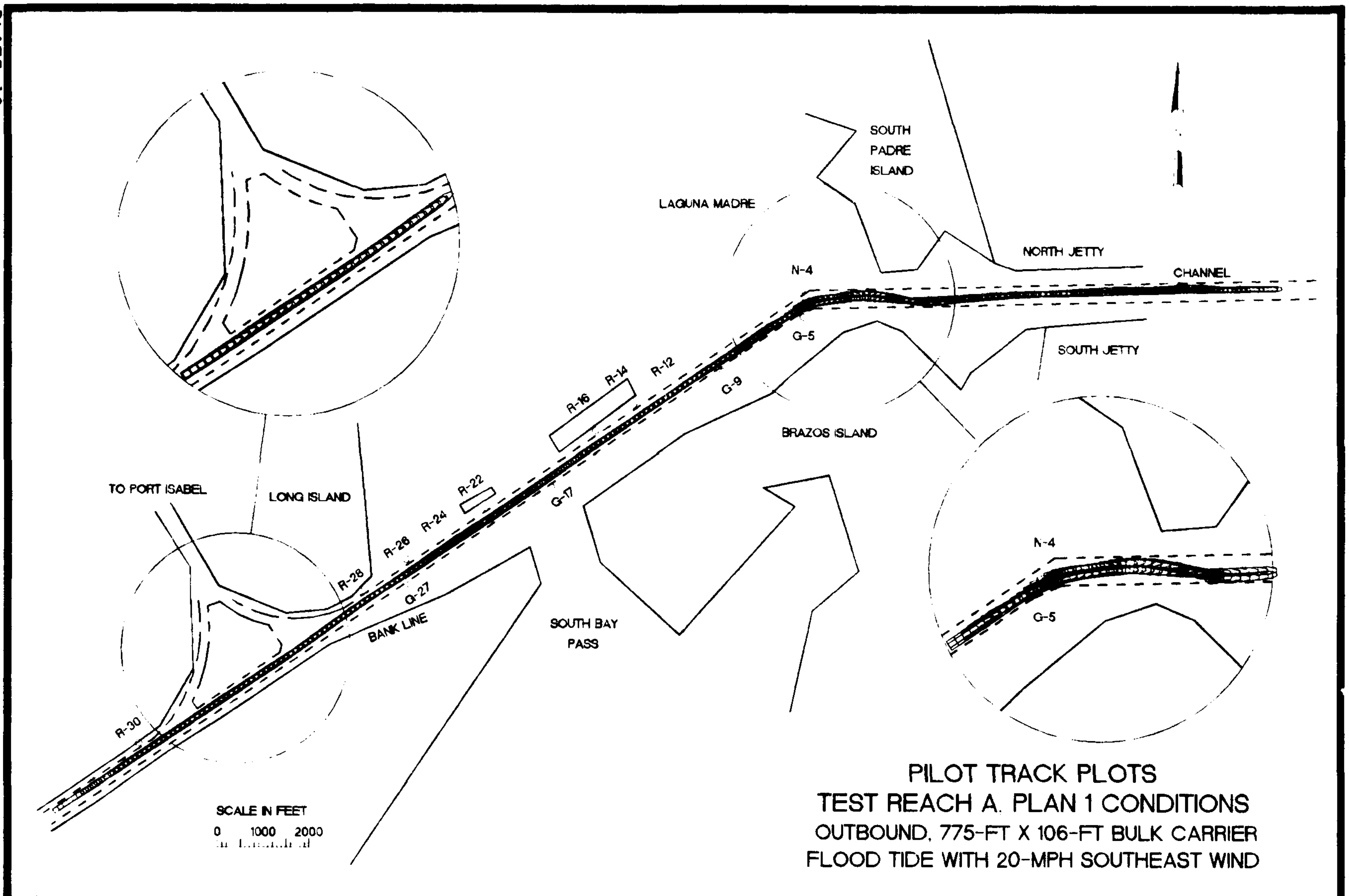
PILOT TRACK PLOTS
TEST REACH A, PLAN 2 CONDITIONS
INBOUND, 775-FT X 106-FT BULK CARRIER
EBB TIDE WITHOUT WIND



PILOT TRACK PLOTS
TEST REACH A, PLAN 3 CONDITIONS
INBOUND. 775-FT X 106-FT BULK CARRIER
EBB TIDE WITHOUT WIND

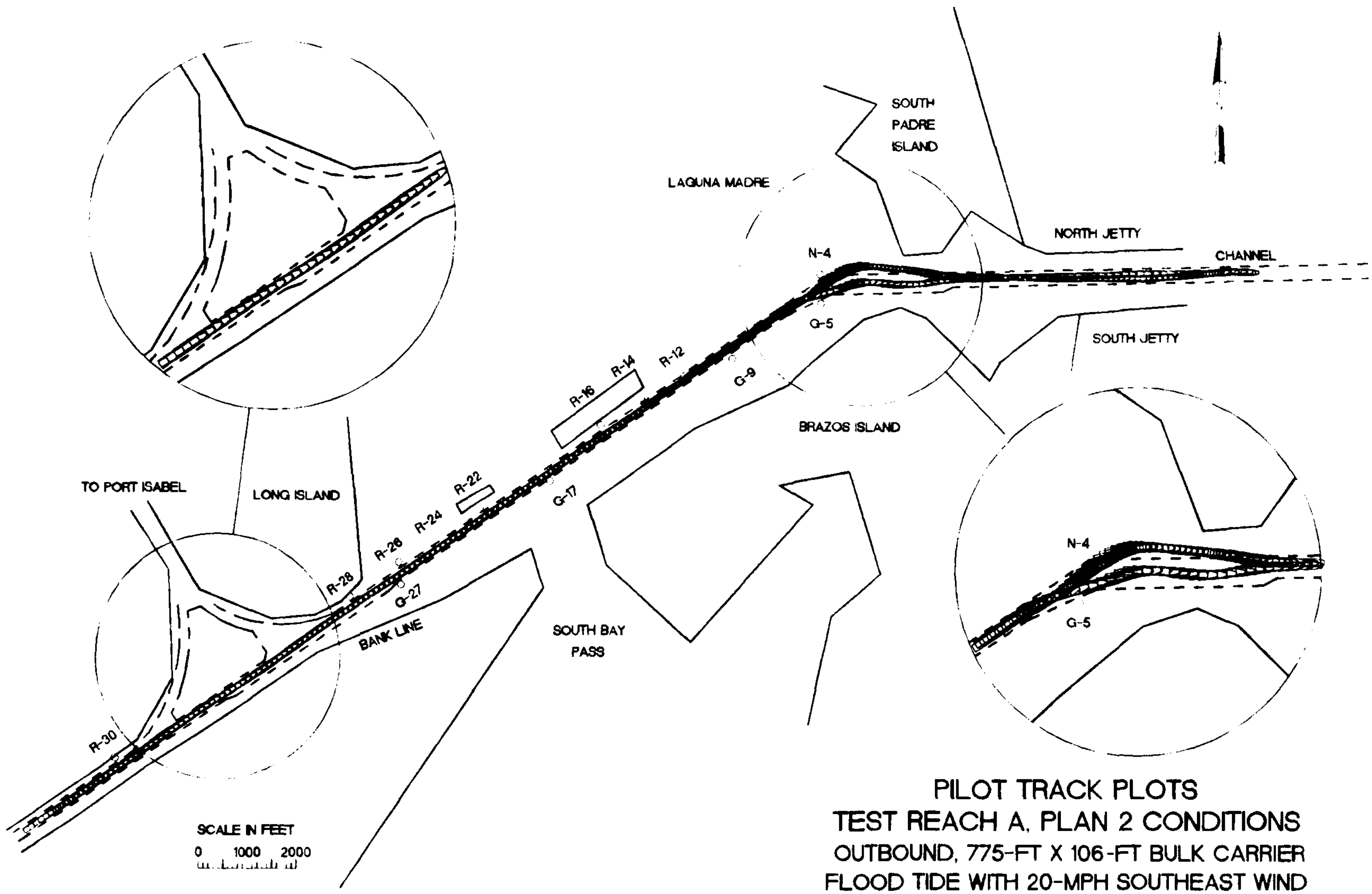


PILOT TRACK PLOTS
TEST REACH A, EXISTING CONDITIONS
OUTBOUND, 594-FT X 96-FT BULK CARRIER
FLOOD TIDE WITH 20-MPH SOUTHEAST WIND

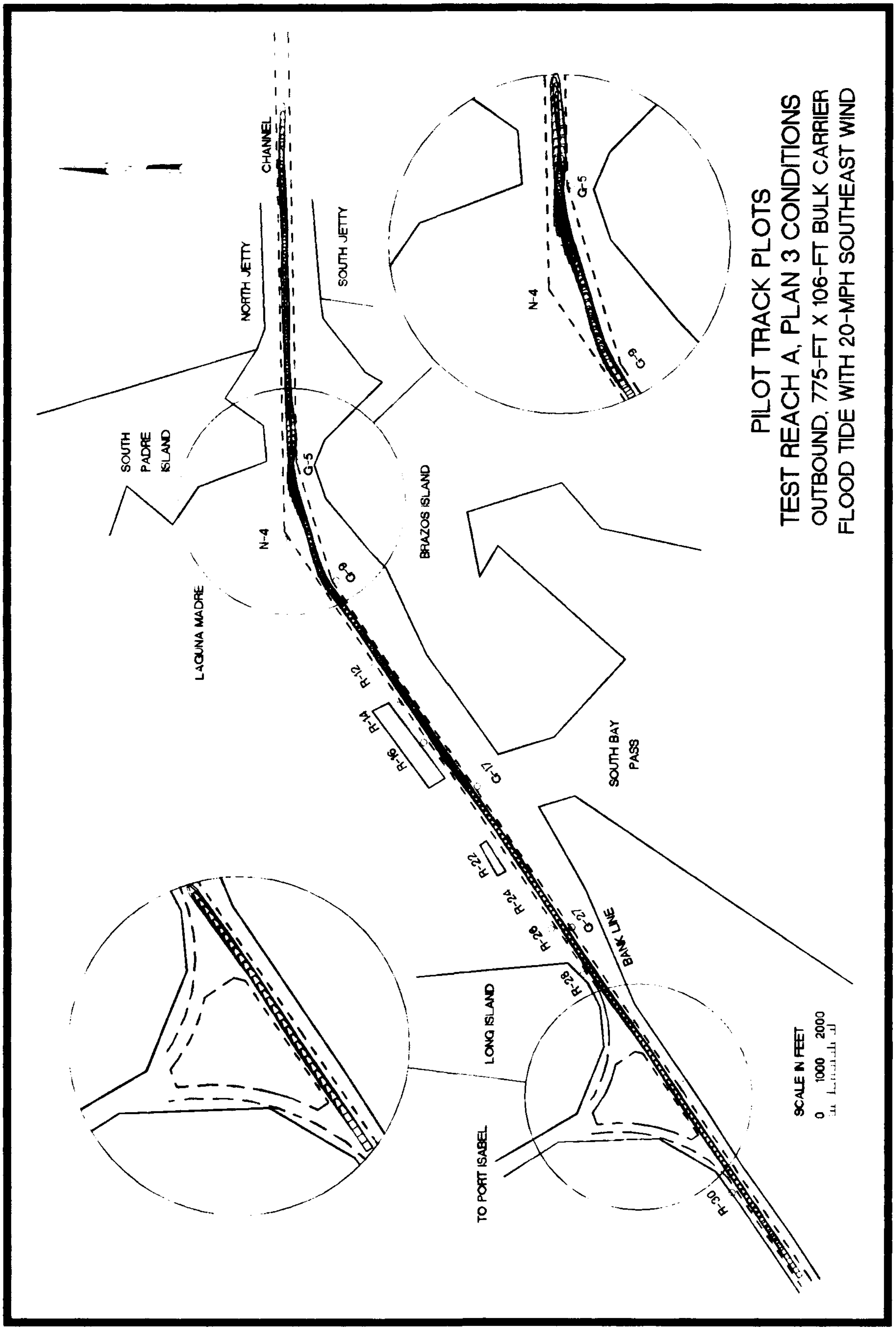


PILOT TRACK PLOTS
TEST REACH A. PLAN 1 CONDITIONS
OUTBOUND, 775-FT X 106-FT BULK CARRIER
FLOOD TIDE WITH 20-MPH SOUTHEAST WIND

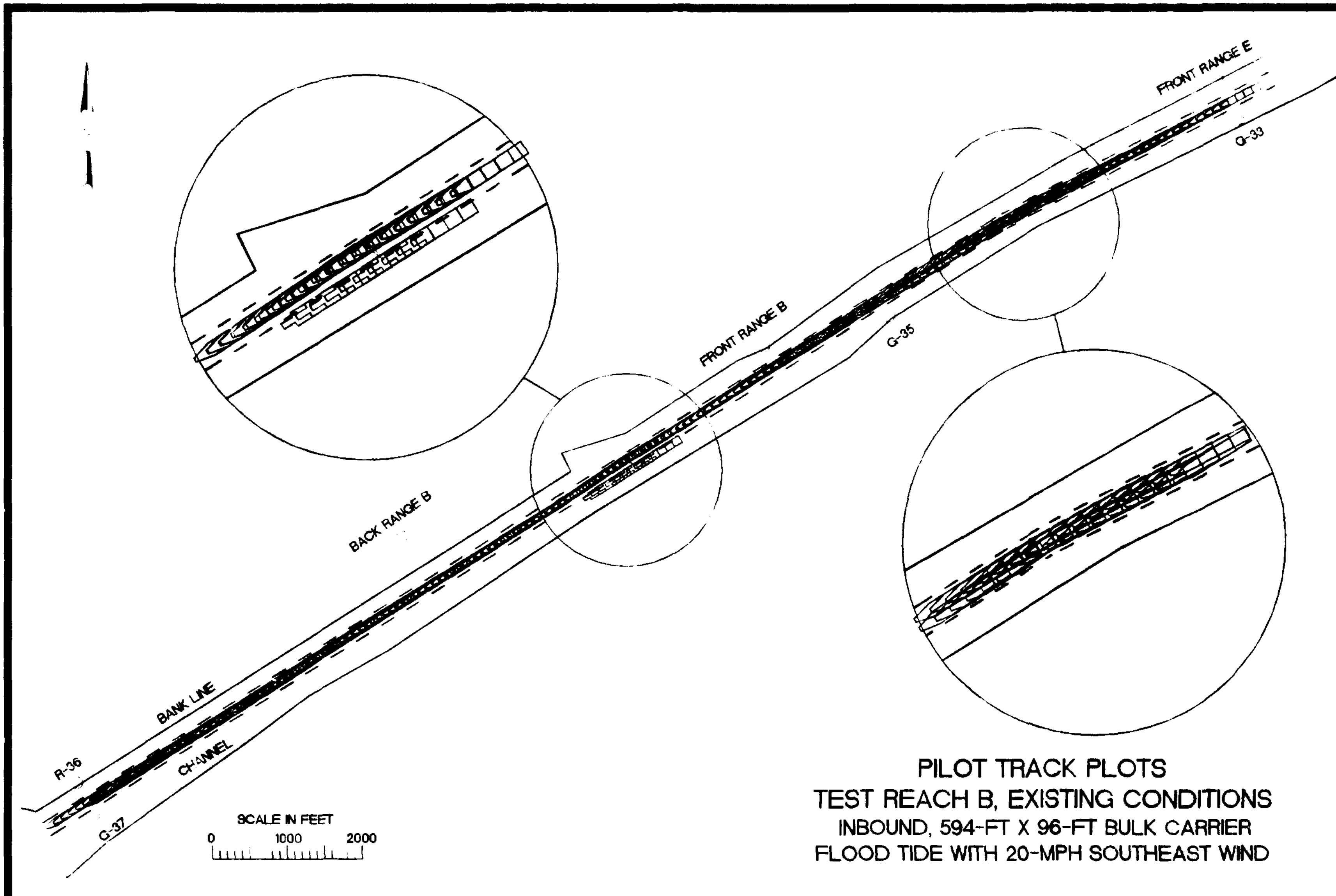
PLATE 10



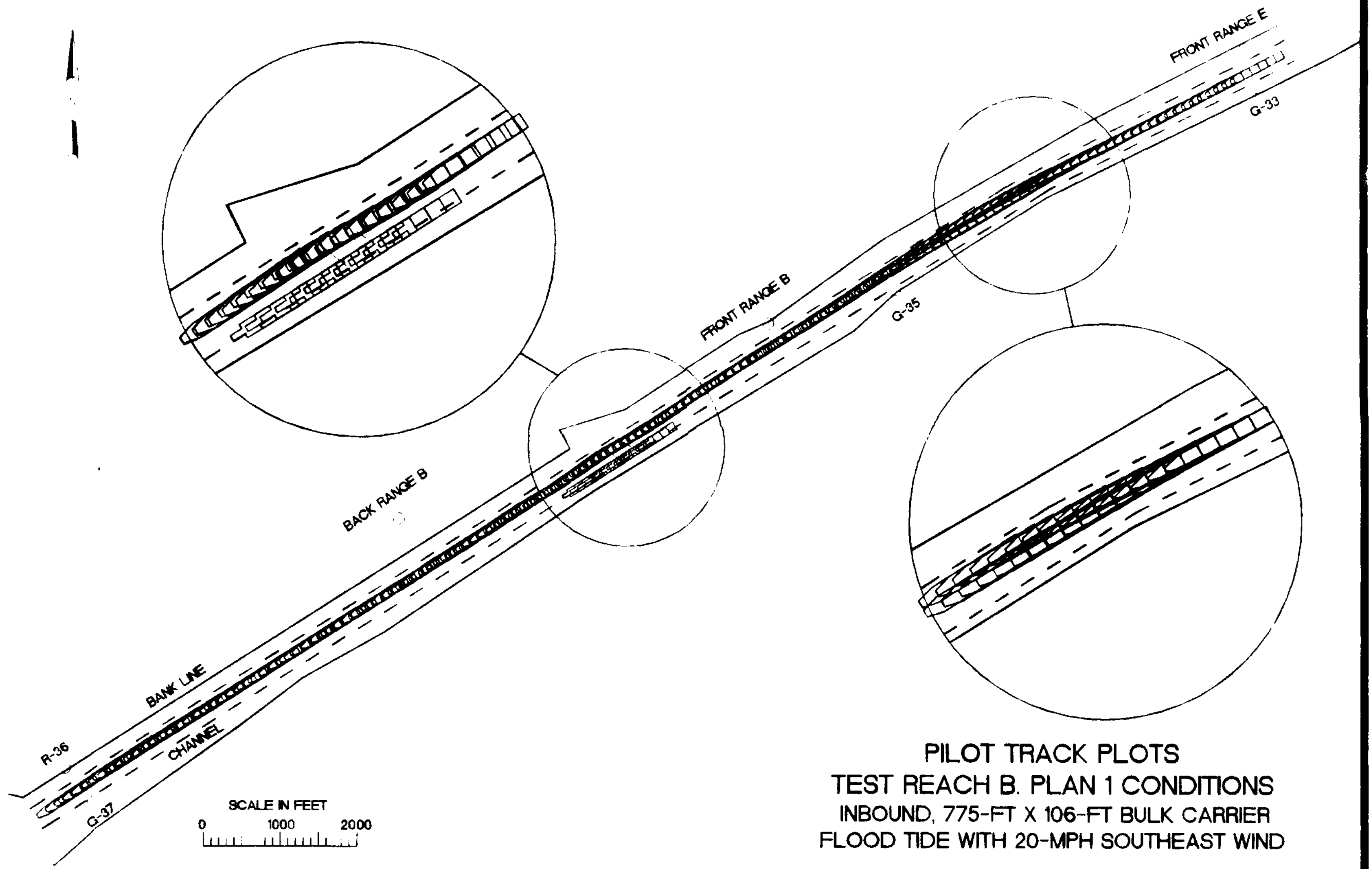
PILOT TRACK PLOTS
TEST REACH A, PLAN 2 CONDITIONS
OUTBOUND, 775-FT X 106-FT BULK CARRIER
FLOOD TIDE WITH 20-MPH SOUTHEAST WIND



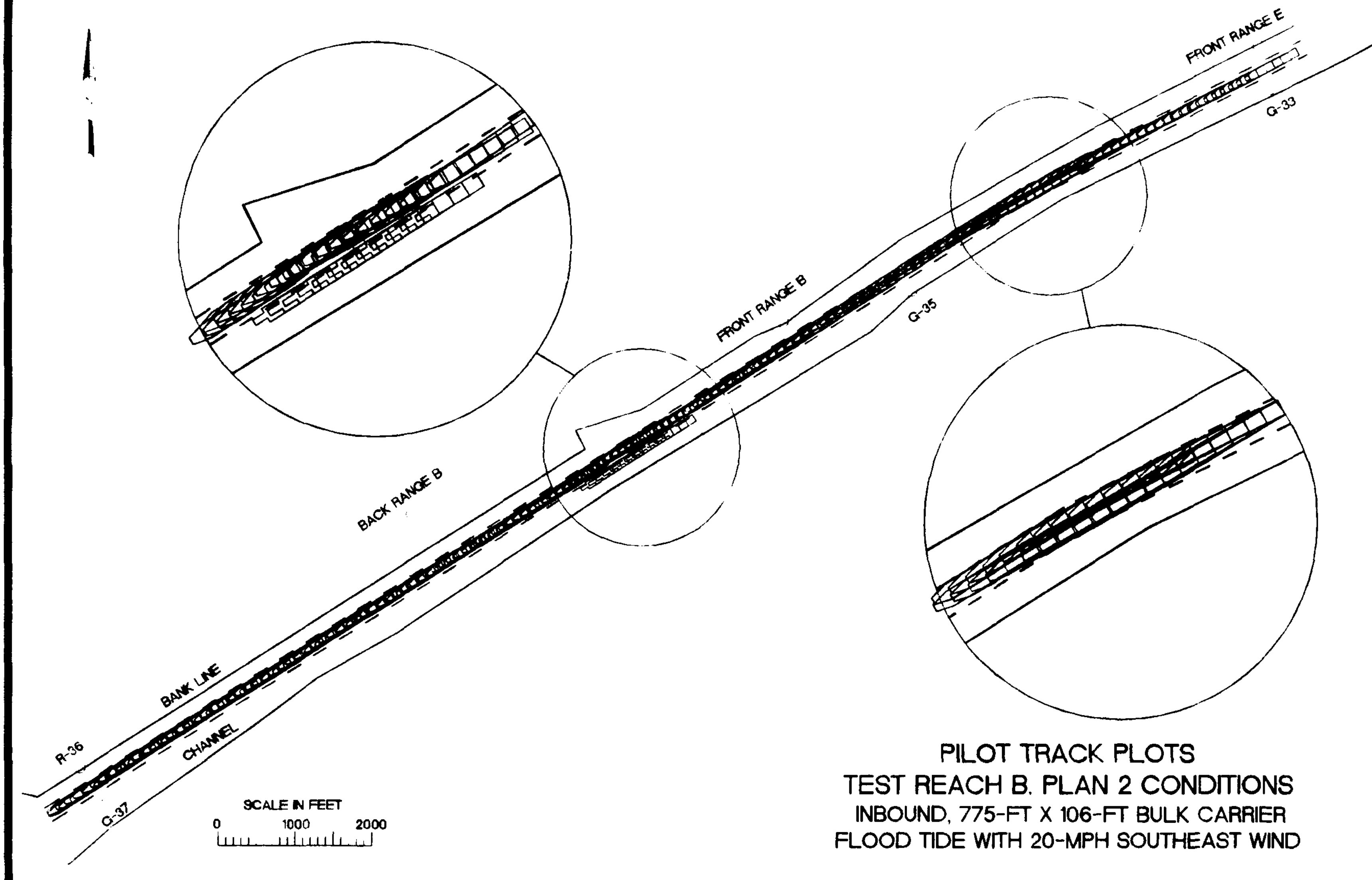
PILOT TRACK PLOTS
TEST REACH A, PLAN 3 CONDITIONS
OUTBOUND, 775-FT X 106-FT BULK CARRIER
FLOOD TIDE WITH 20-MPH SOUTHEAST WIND



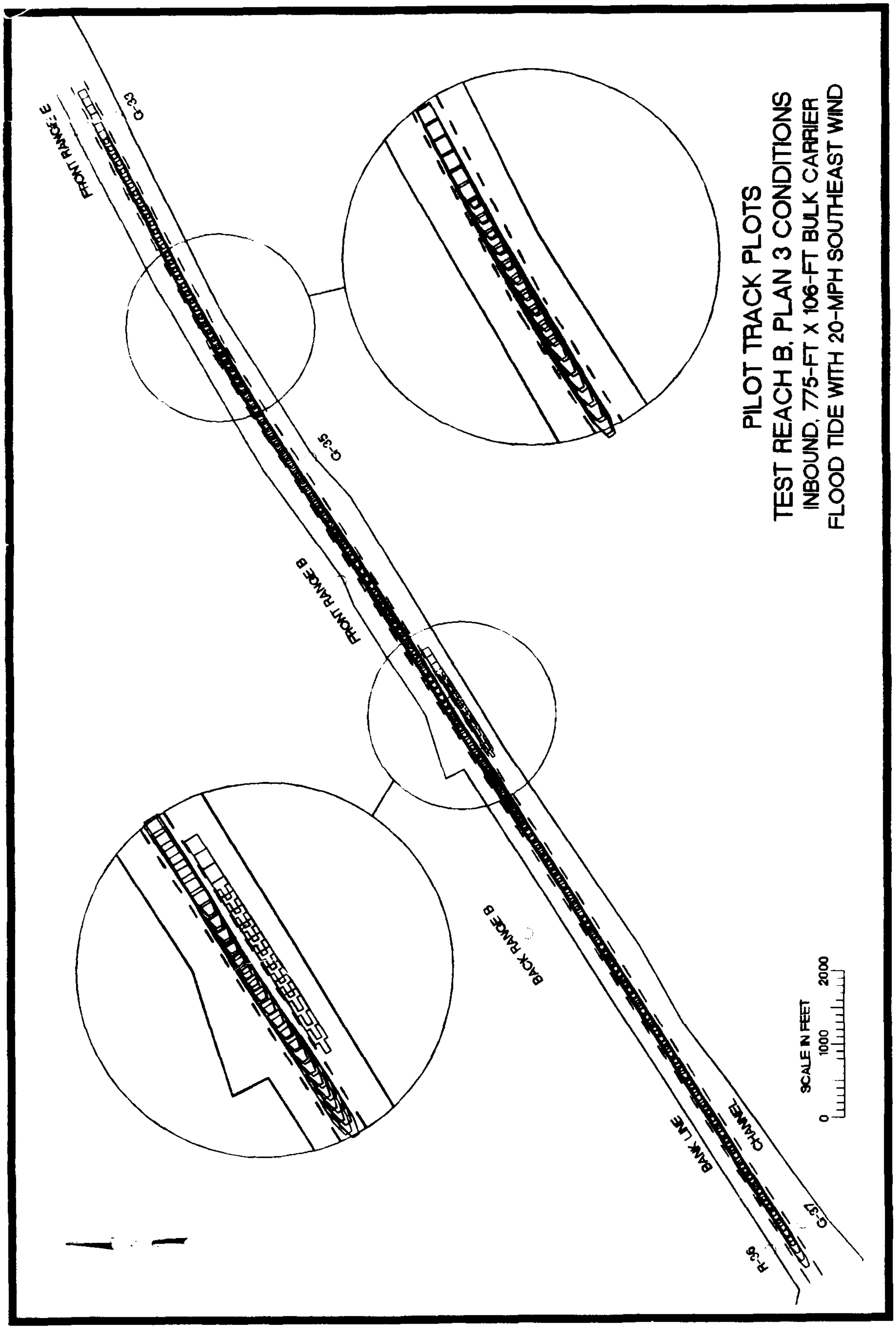
PILOT TRACK PLOTS
TEST REACH B, EXISTING CONDITIONS
INBOUND, 594-FT X 96-FT BULK CARRIER
FLOOD TIDE WITH 20-MPH SOUTHEAST WIND



PILOT TRACK PLOTS
TEST REACH B. PLAN 1 CONDITIONS
INBOUND, 775-FT X 106-FT BULK CARRIER
FLOOD TIDE WITH 20-MPH SOUTHEAST WIND

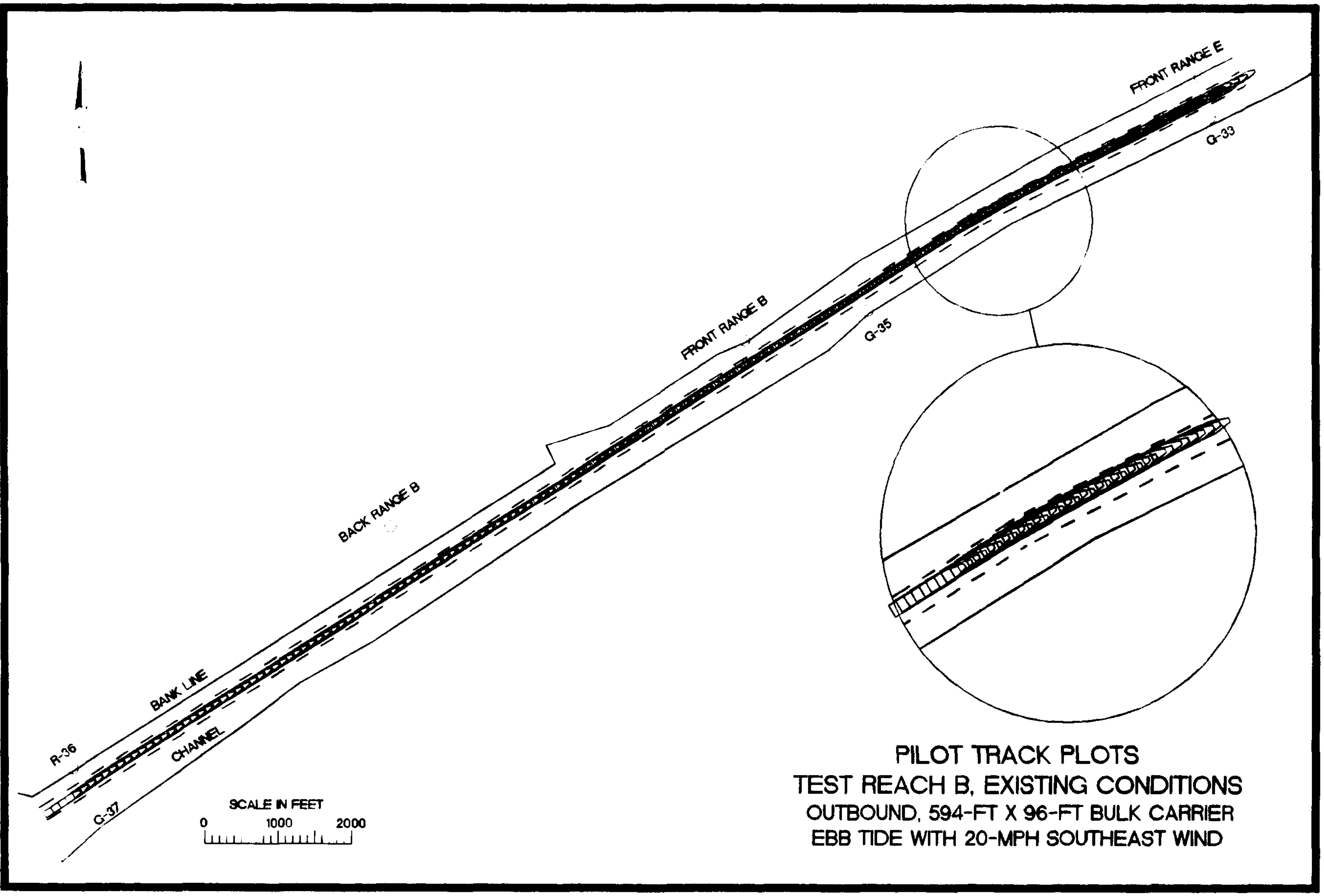


PILOT TRACK PLOTS
TEST REACH B. PLAN 2 CONDITIONS
INBOUND, 775-FT X 106-FT BULK CARRIER
FLOOD TIDE WITH 20-MPH SOUTHEAST WIND

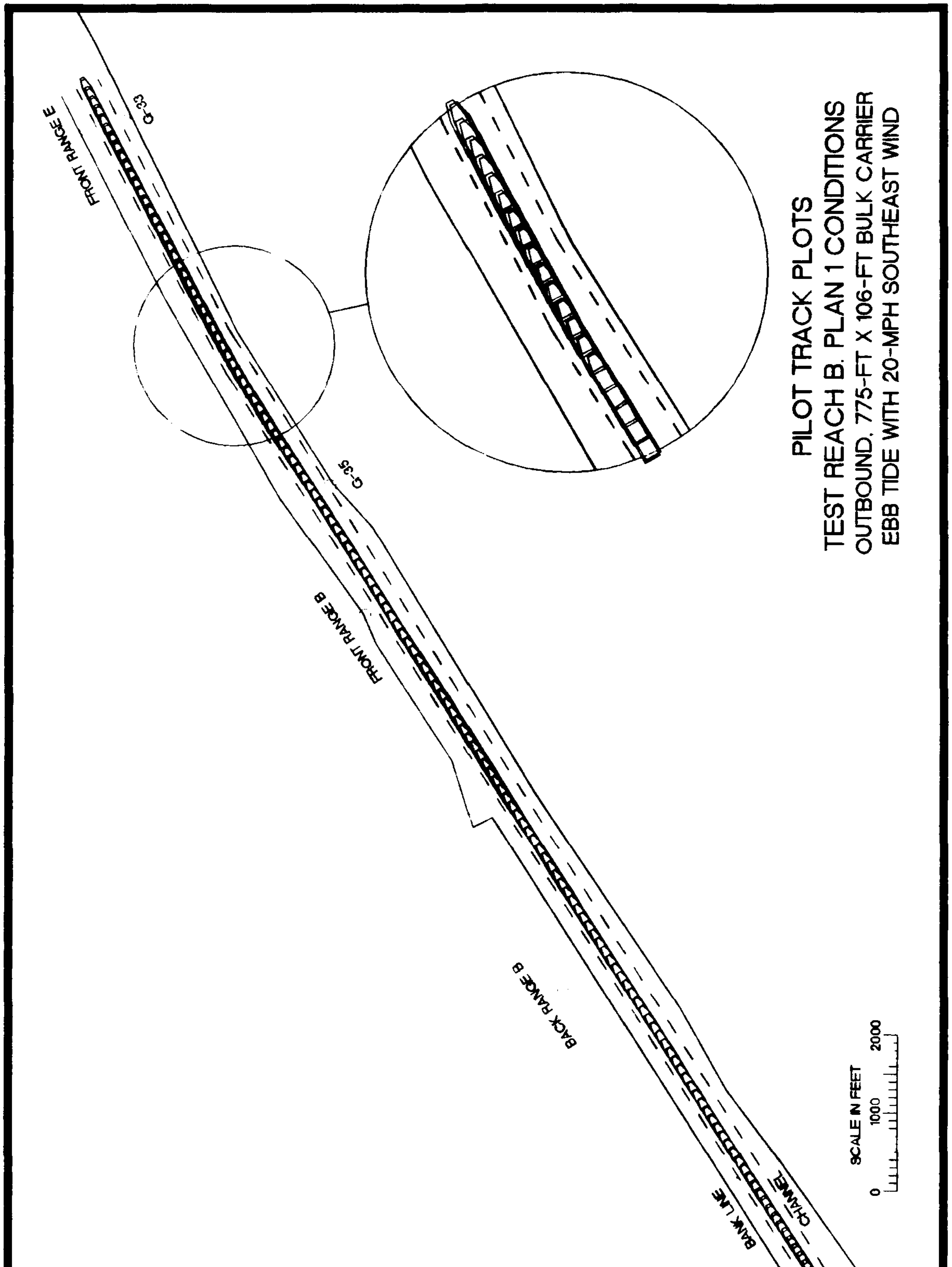


PILOT TRACK PLOTS
TEST REACH B, PLAN 3 CONDITIONS
INBOUND, 775-FT X 106-FT BULK CARRIER
FLOOD TIDE WITH 20-MPH SOUTHEAST WIND

PLATE 16



PILOT TRACK PLOTS
TEST REACH B, EXISTING CONDITIONS
OUTBOUND, 594-FT X 96-FT BULK CARRIER
EBB TIDE WITH 20-MPH SOUTHEAST WIND



PILOT TRACK PLOTS
TEST REACH B. PLAN 1 CONDITIONS
OUTBOUND, 775-FT X 106-FT BULK CARRIER
EBB TIDE WITH 20-MPH SOUTHEAST WIND

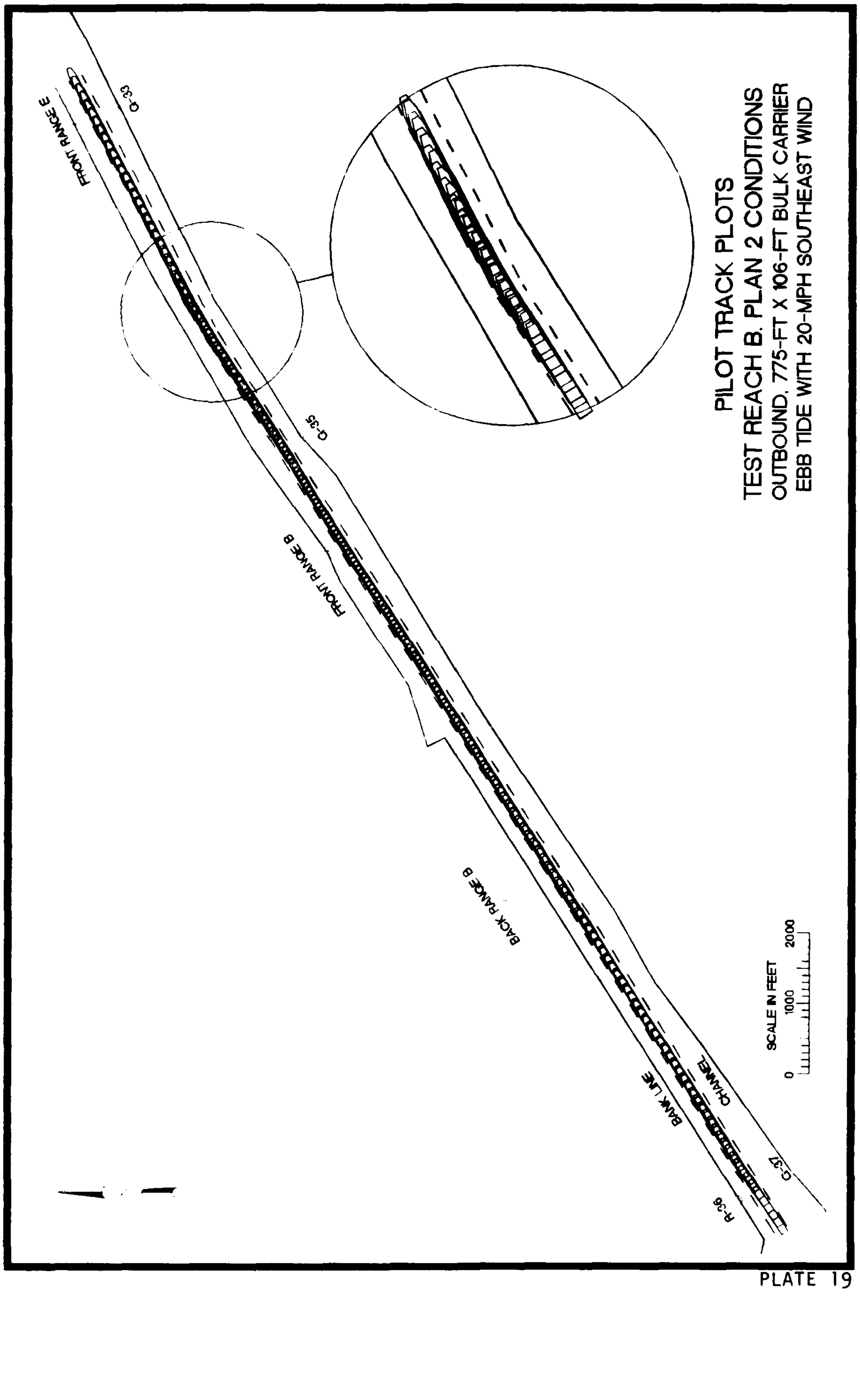

PILOT TRACK PLOTS
TEST REACH B, PLAN 2 CONDITIONS
OUTBOUND, 775-FT X 106-FT BULK CARRIER
EBB TIDE WITH 20-MPH SOUTHEAST WIND
FRONT RANGE E
G-33
G-35
FRONT RANGE B
BACK RANGE B
BANK LINE
CHANNEL
G-37
R-36
SCALE IN FEET
0
1000
2000

PLATE 19

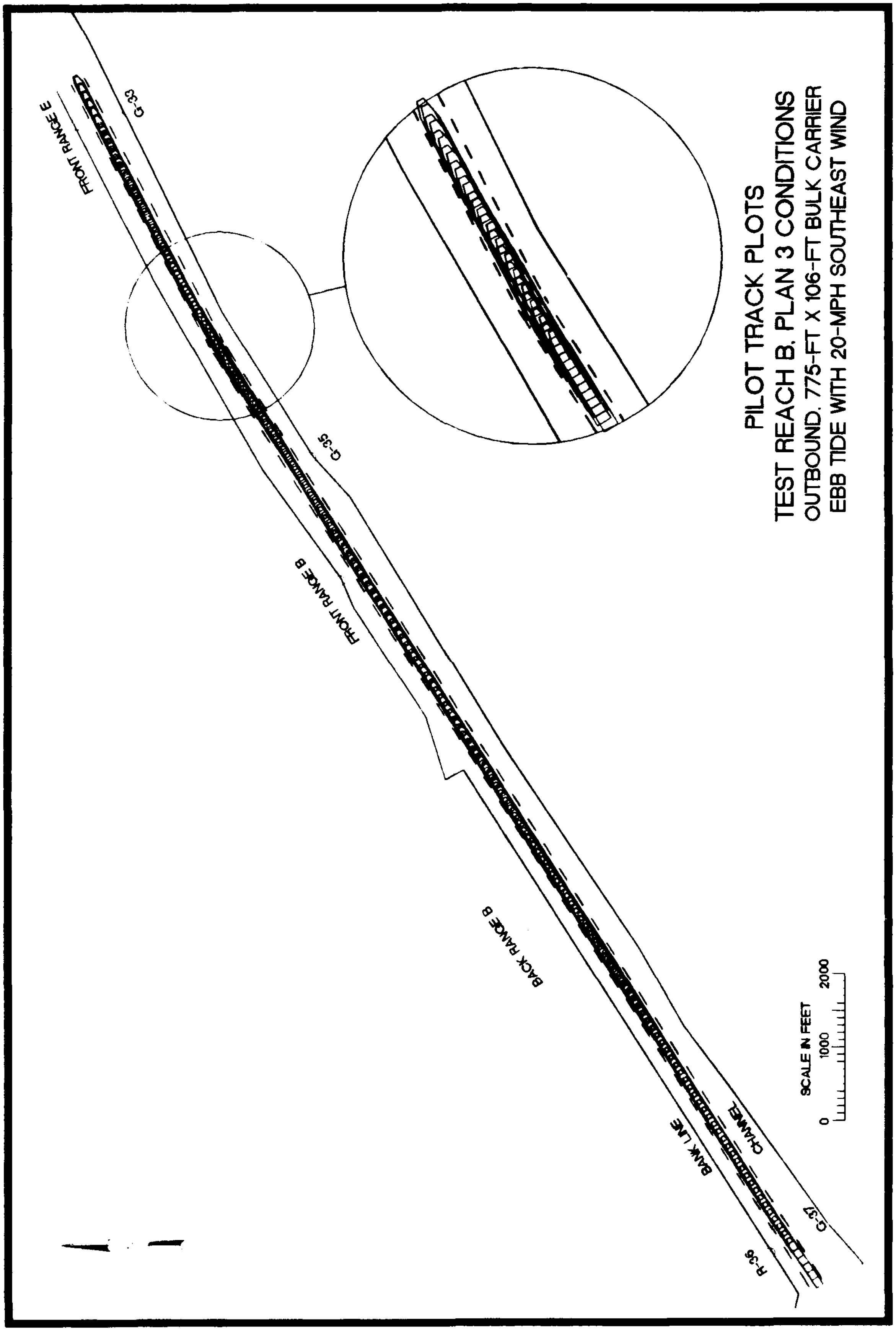
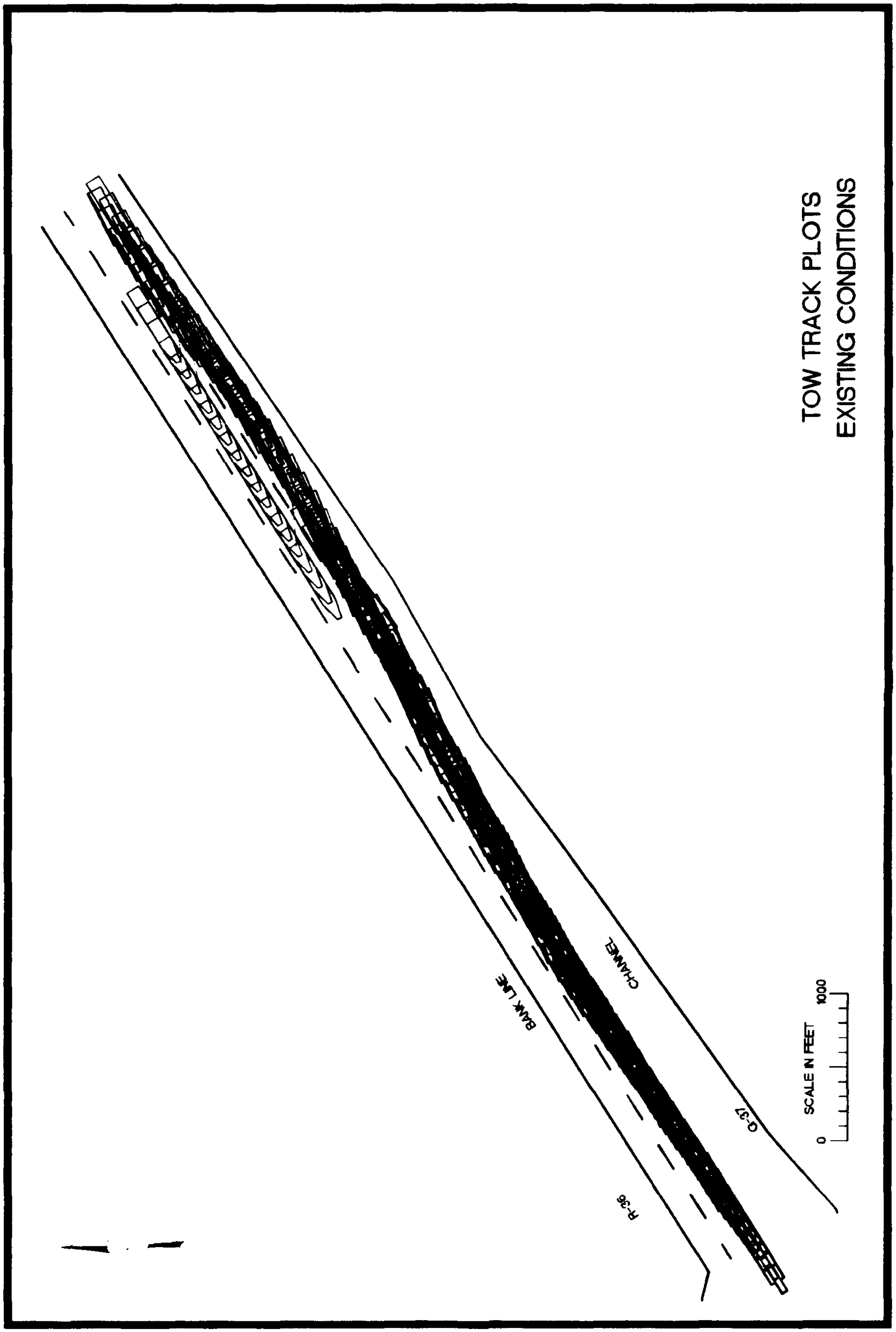

PILOT TRACK PLOTS
TEST REACH B, PLAN 3 CONDITIONS
OUTBOUND, 775-FT X 106-FT BULK CARRIER
EBB TIDE WITH 20-MPH SOUTHEAST WIND
FRONT RANGE E
G-33
G-35
FRONT RANGE B
BACK RANGE B
BANK LINE
CHANNEL
G-37
R-36
SCALE IN FEET
0
1000
2000

PLATE 20



TOW TRACK PLOTS
EXISTING CONDITIONS

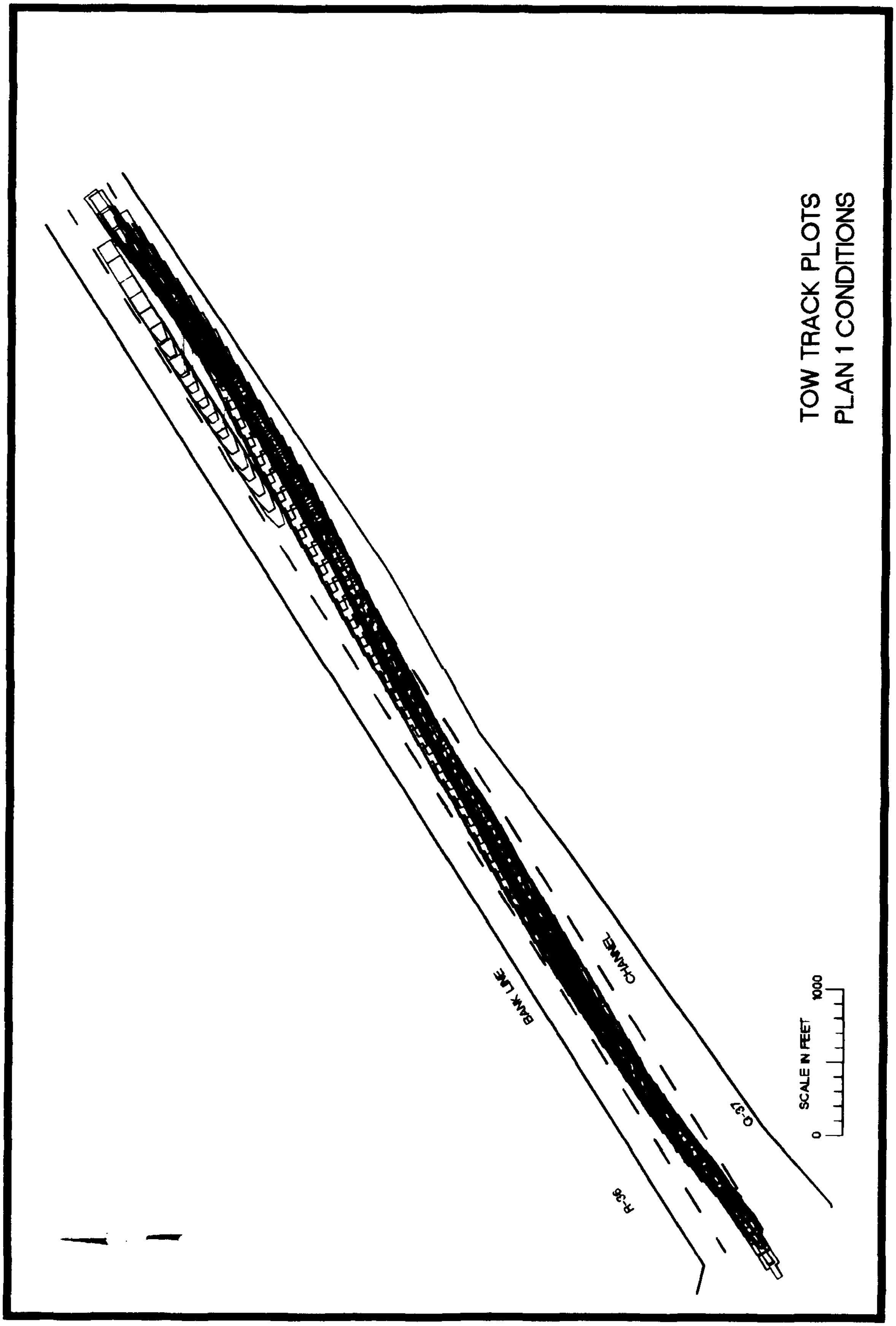

TOW TRACK PLOTS
PLAN 1 CONDITIONS
BANK LINE
CHANNEL
R-36
Q-37
SCALE IN FEET
0
1000

PLATE 22

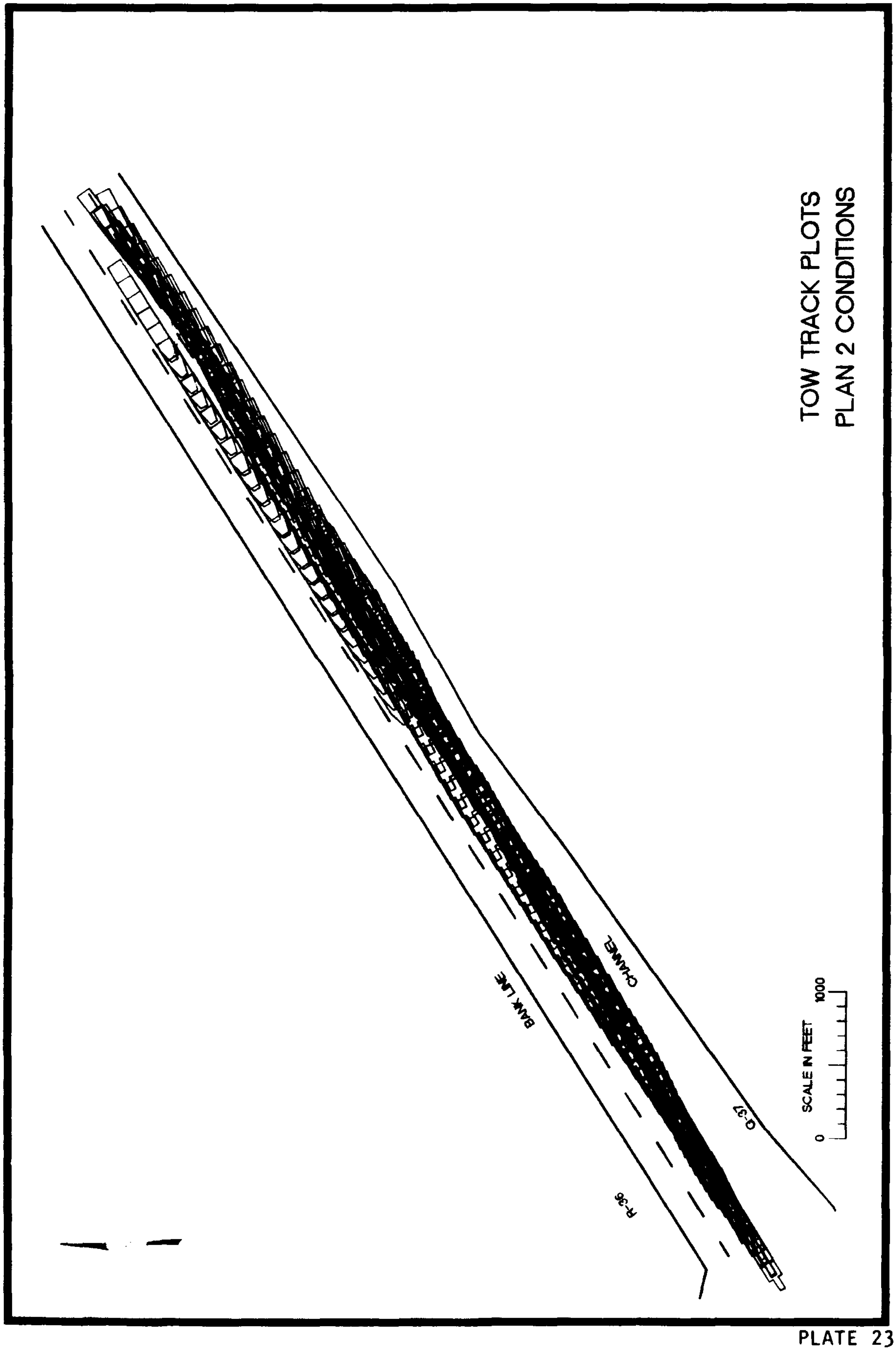

TOW TRACK PLOTS
PLAN 2 CONDITIONS
BANK LINE
CHANNEL
R-36
Q-37
SCALE IN FEET
0
1000

PLATE 23

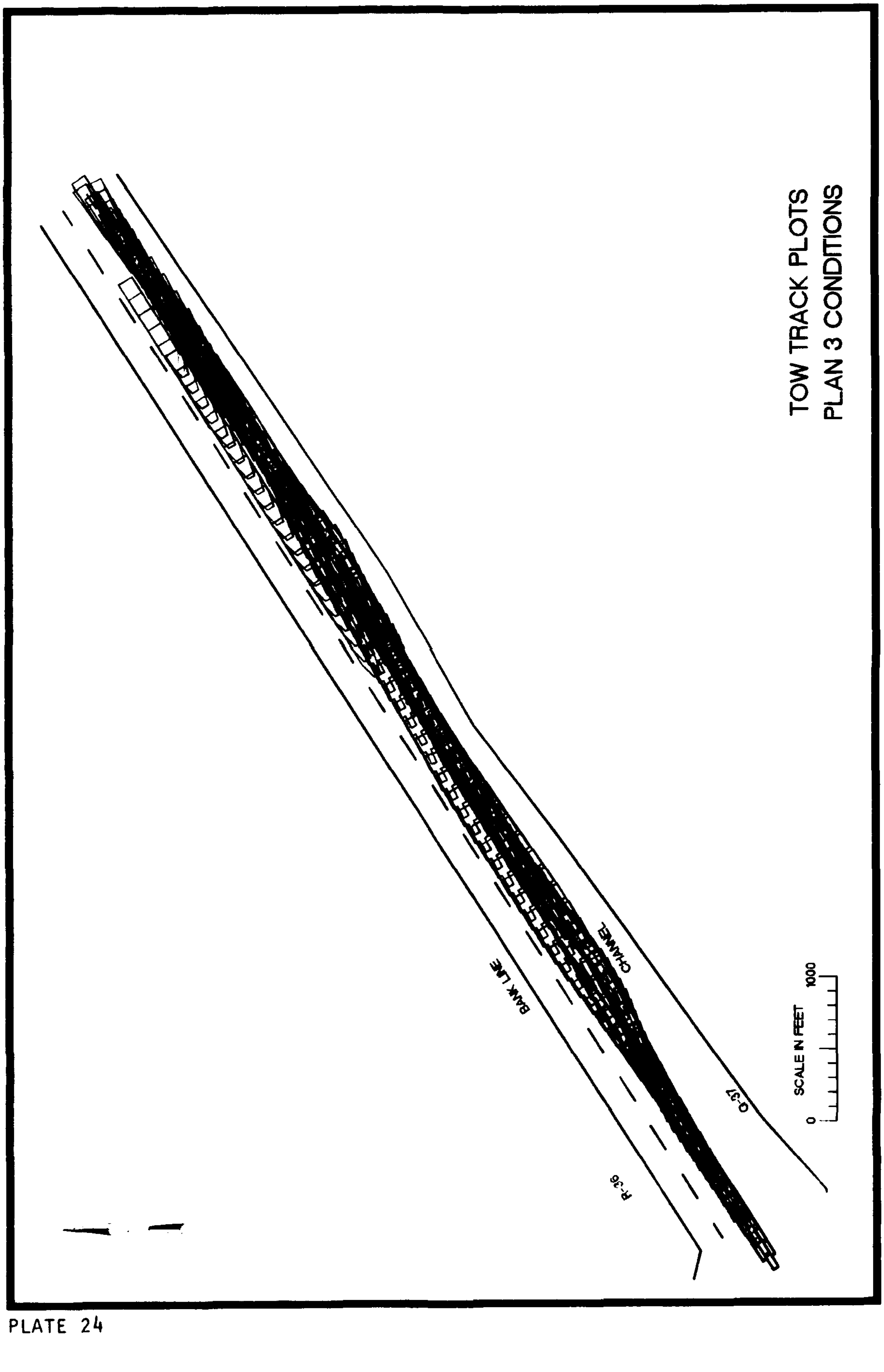
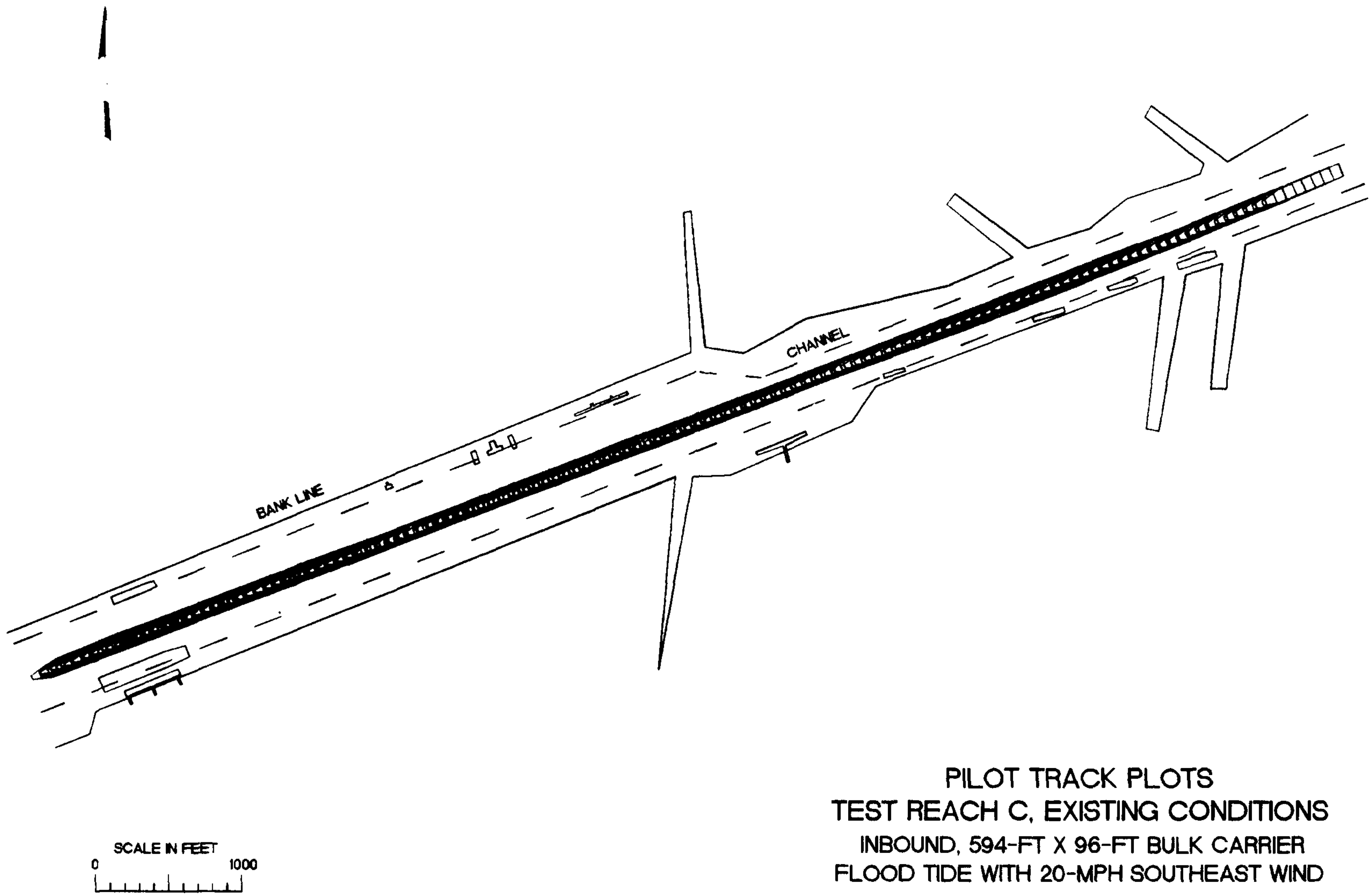
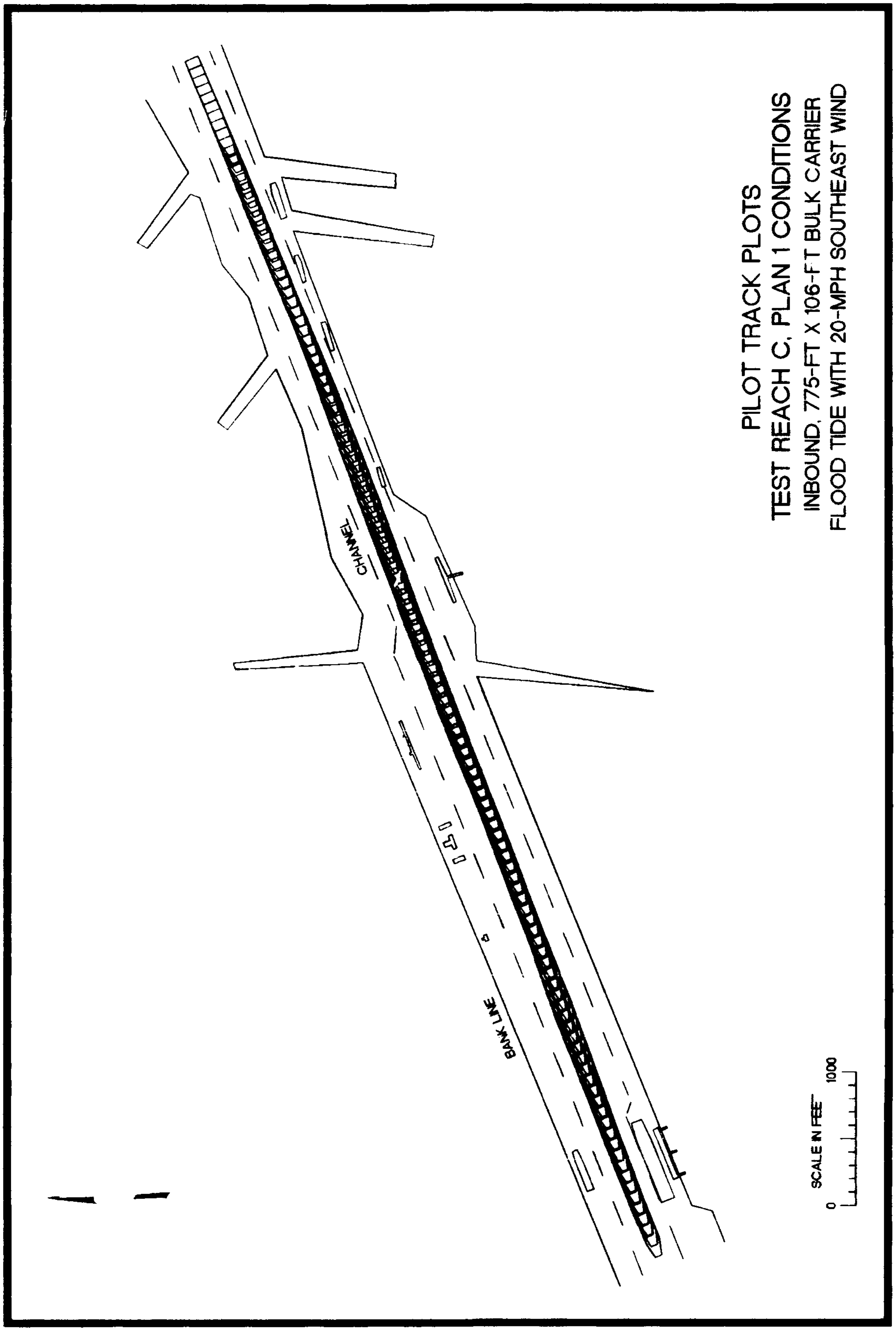
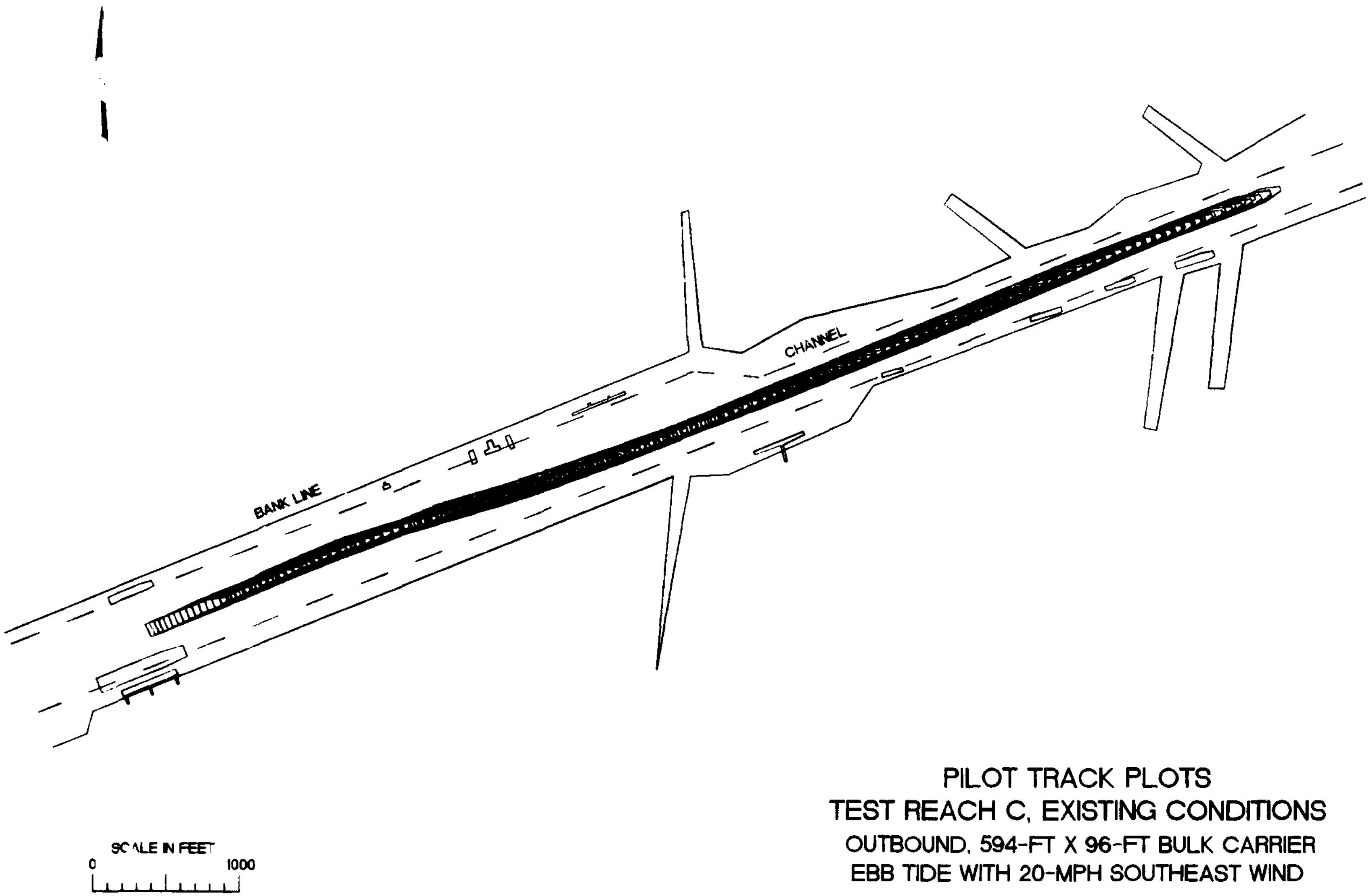

TOW TRACK PLOTS
PLAN 3 CONDITIONS
CHANNEL
BANK LINE
SCALE IN FEET
0
1000
R-36
Q-37

PLATE 24

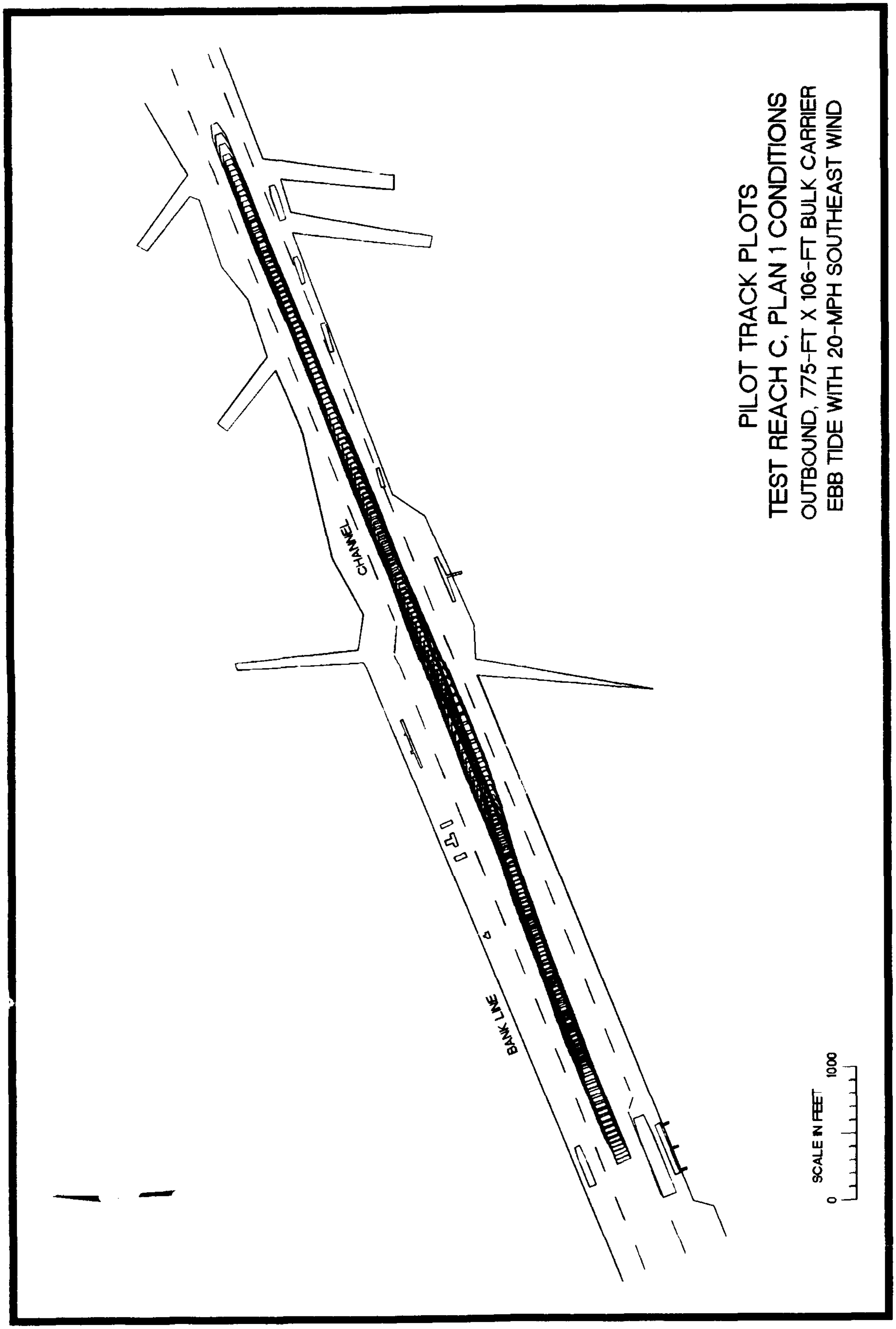


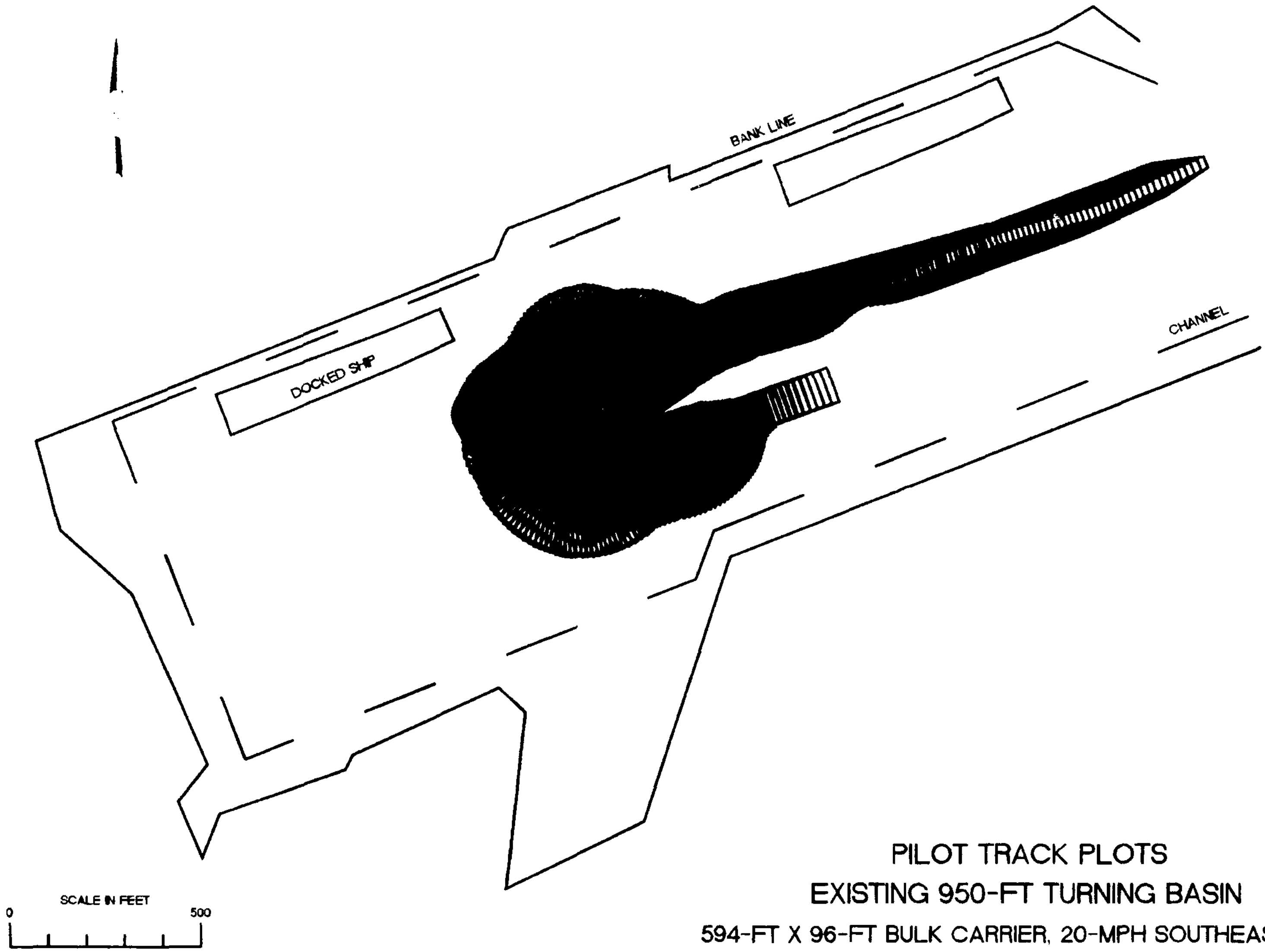
PILOT TRACK PLOTS
TEST REACH C, EXISTING CONDITIONS
INBOUND, 594-FT X 96-FT BULK CARRIER
FLOOD TIDE WITH 20-MPH SOUTHEAST WIND


PILOT TRACK PLOTS
TEST REACH C, PLAN 1 CONDITIONS
INBOUND, 775-FT X 106-FT BULK CARRIER
FLOOD TIDE WITH 20-MPH SOUTHEAST WIND
CHANNEL
BANK LINE
SCALE IN FEET
0
1000

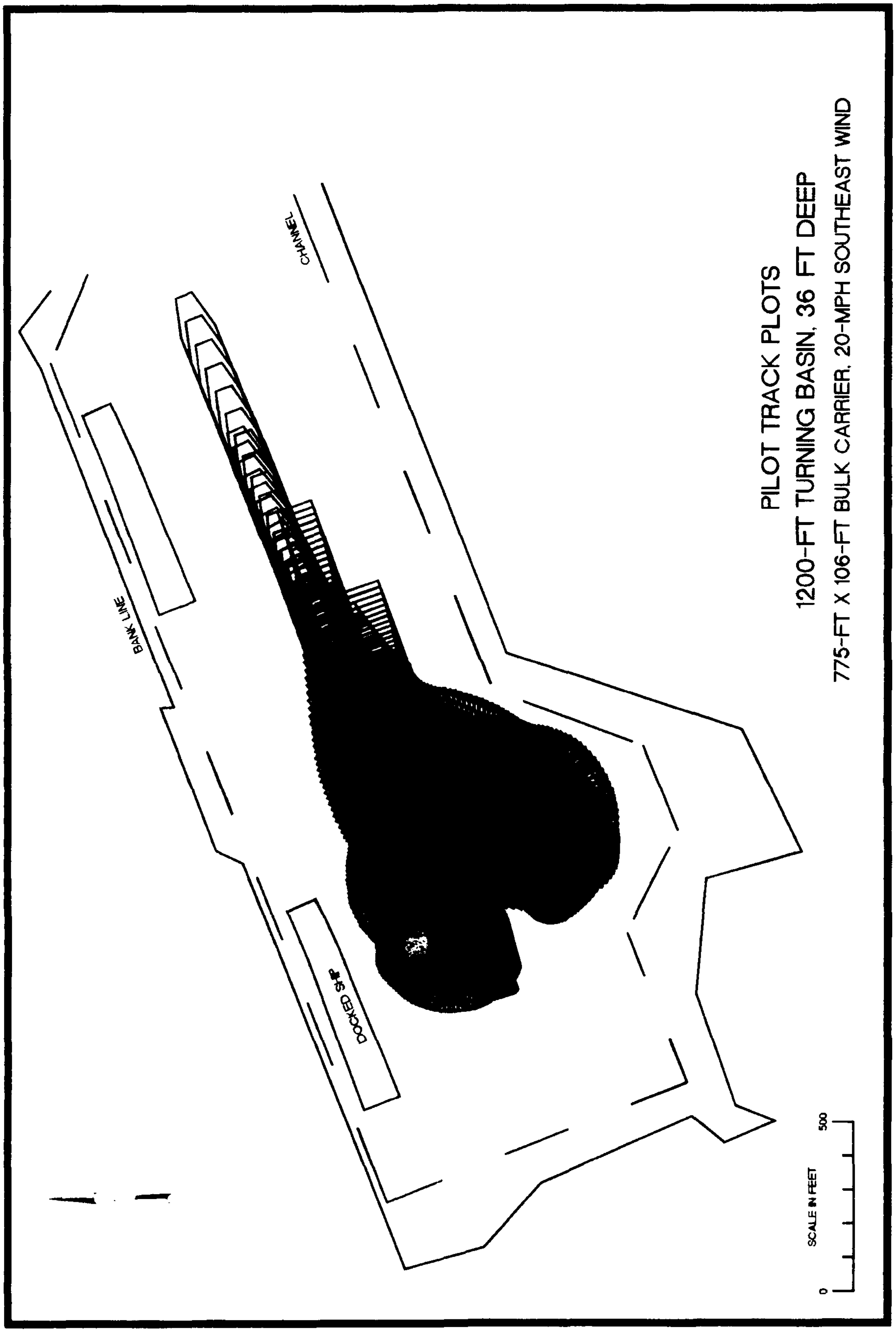


PILOT TRACK PLOTS
TEST REACH C, EXISTING CONDITIONS
OUTBOUND, 594-FT X 96-FT BULK CARRIER
EBB TIDE WITH 20-MPH SOUTHEAST WIND


PILOT TRACK PLOTS
TEST REACH C, PLAN 1 CONDITIONS
OUTBOUND, 775-FT X 106-FT BULK CARRIER
EBB TIDE WITH 20-MPH SOUTHEAST WIND
CHANNEL
BANK LINE
SCALE IN FEET
0
1000

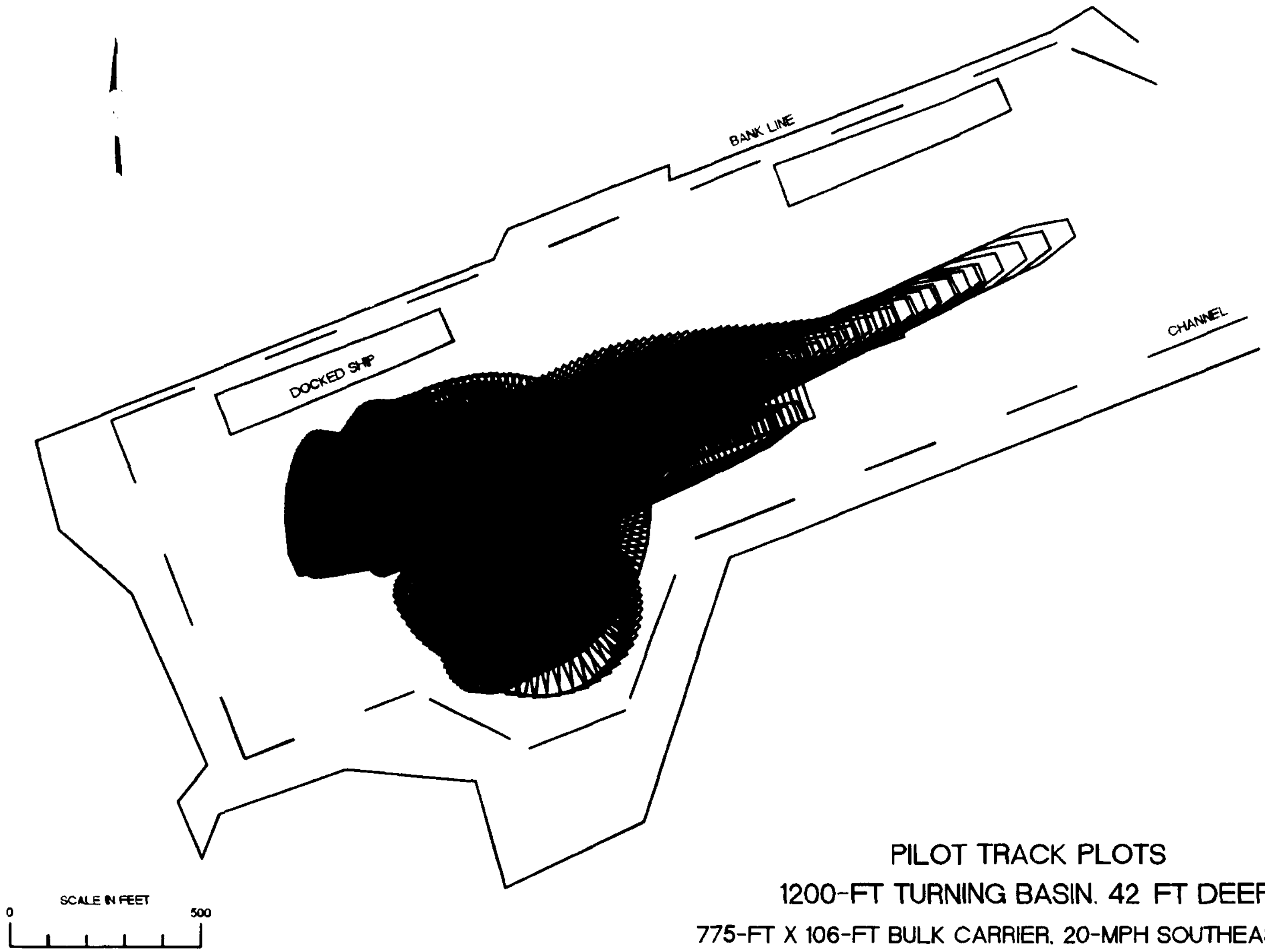


PILOT TRACK PLOTS
EXISTING 950-FT TURNING BASIN
594-FT X 96-FT BULK CARRIER, 20-MPH SOUTHEAST WIND



PILOT TRACK PLOTS
1200-FT TURNING BASIN, 36 FT DEEP
775-FT X 106-FT BULK CARRIER, 20-MPH SOUTHEAST WIND

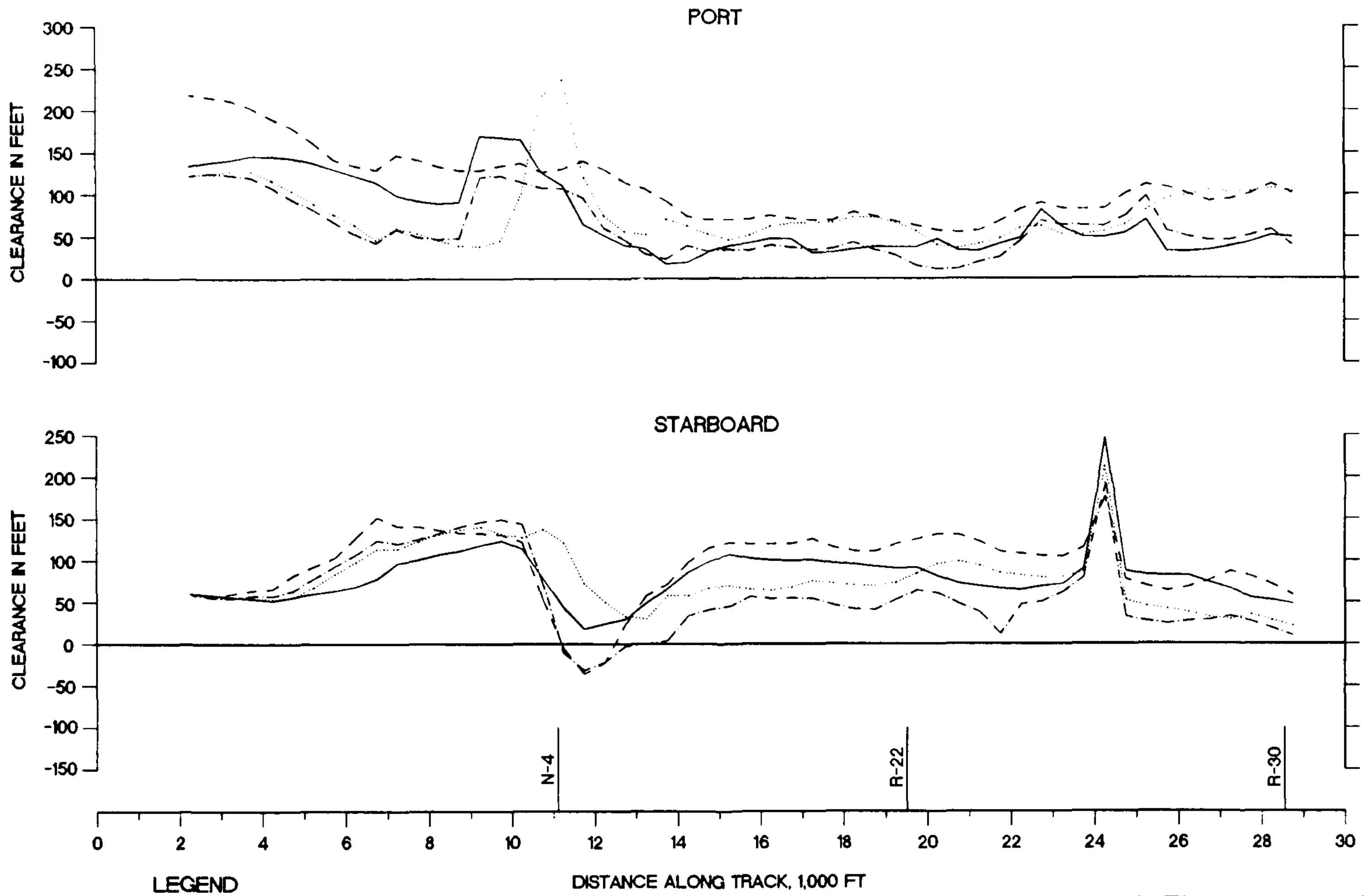
PLATE 30



PILOT TRACK PLOTS

1200-FT TURNING BASIN, 42 FT DEEP

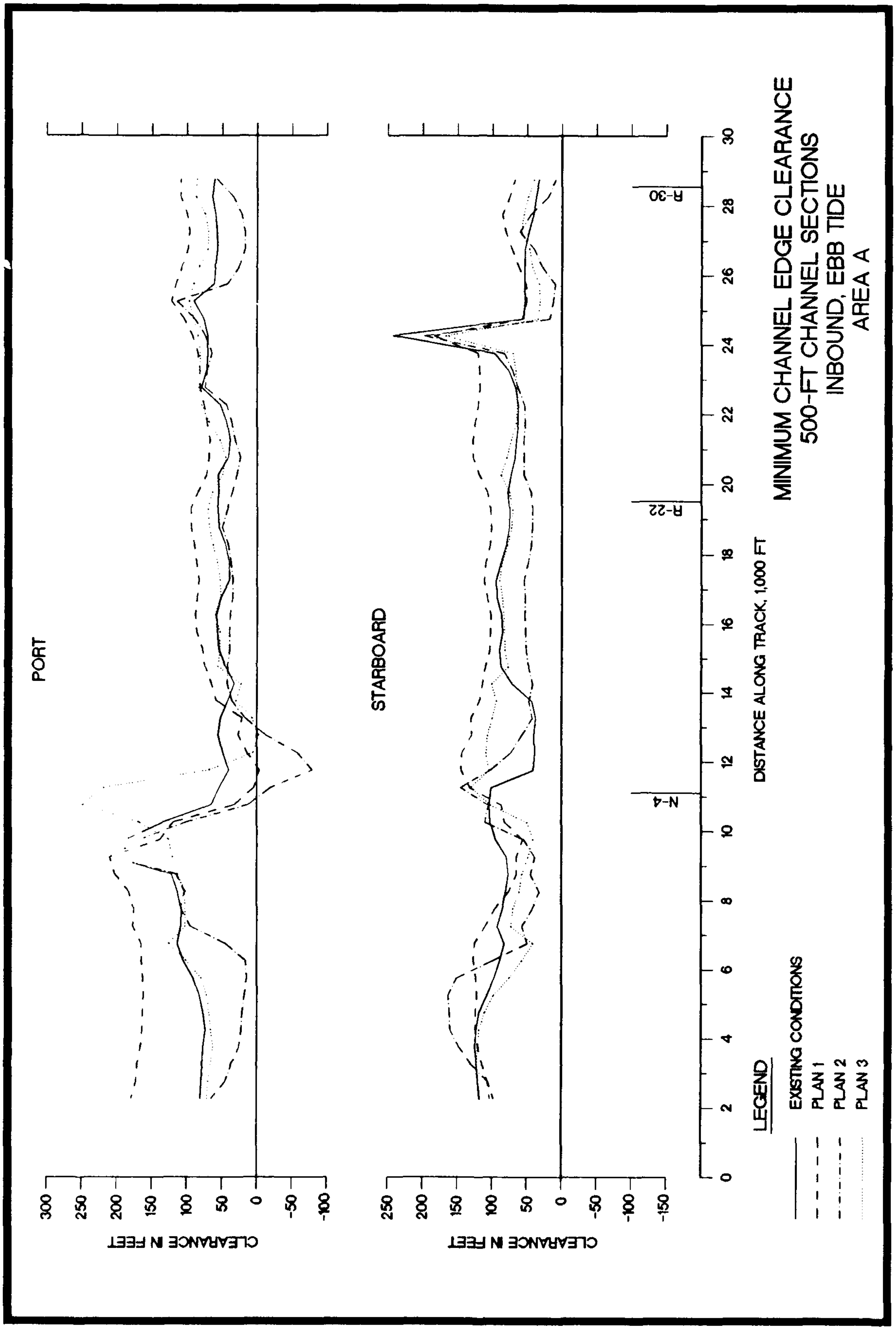
775-FT X 106-FT BULK CARRIER, 20-MPH SOUTHEAST WIND



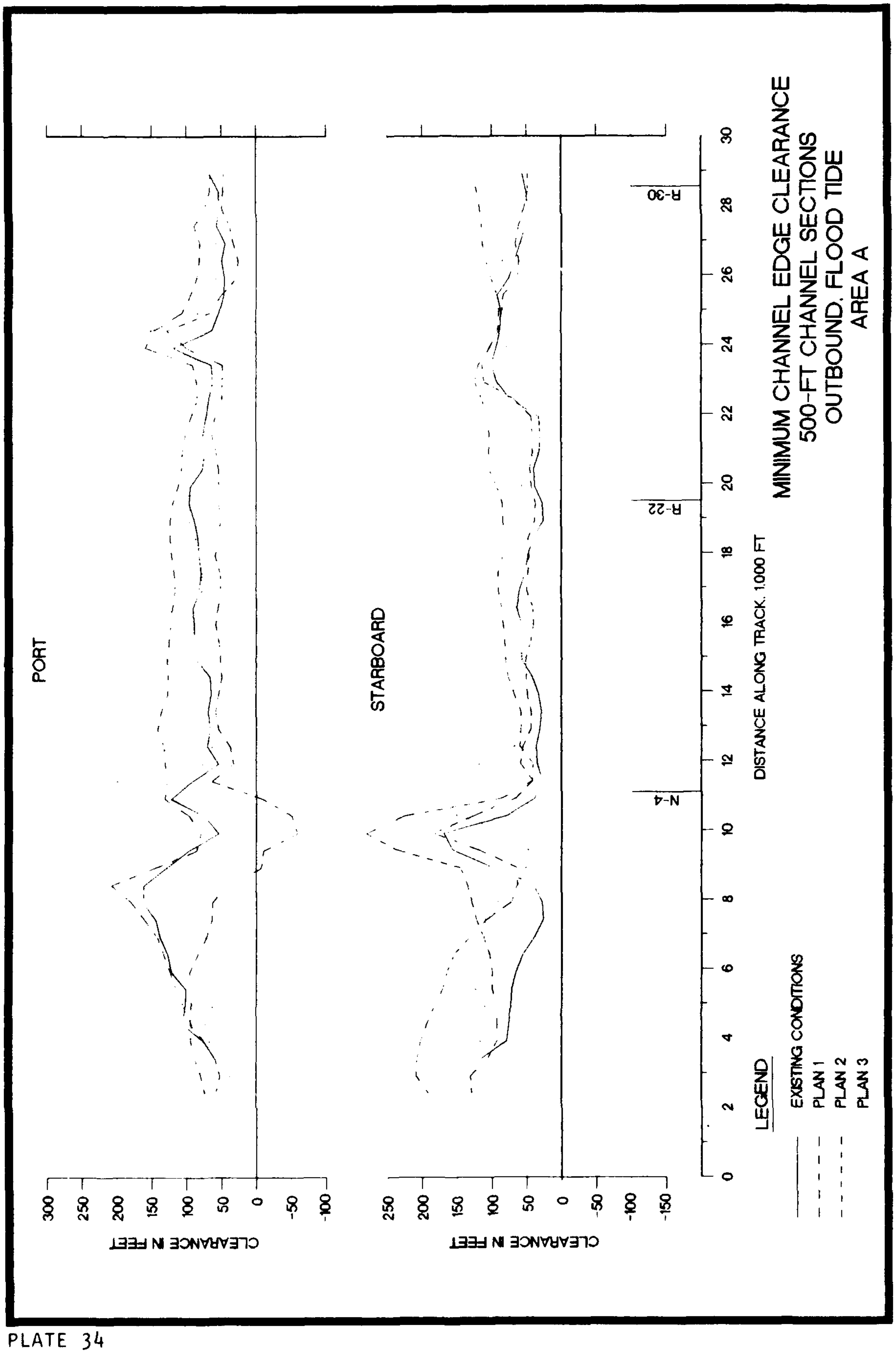
LEGEND

EXISTING CONDITIONS
PLAN 1
PLAN 2
PLAN 3

MINIMUM CHANNEL EDGE CLEARANCE
500-FT CHANNEL SECTIONS
INBOUND, FLOOD TIDE
AREA A

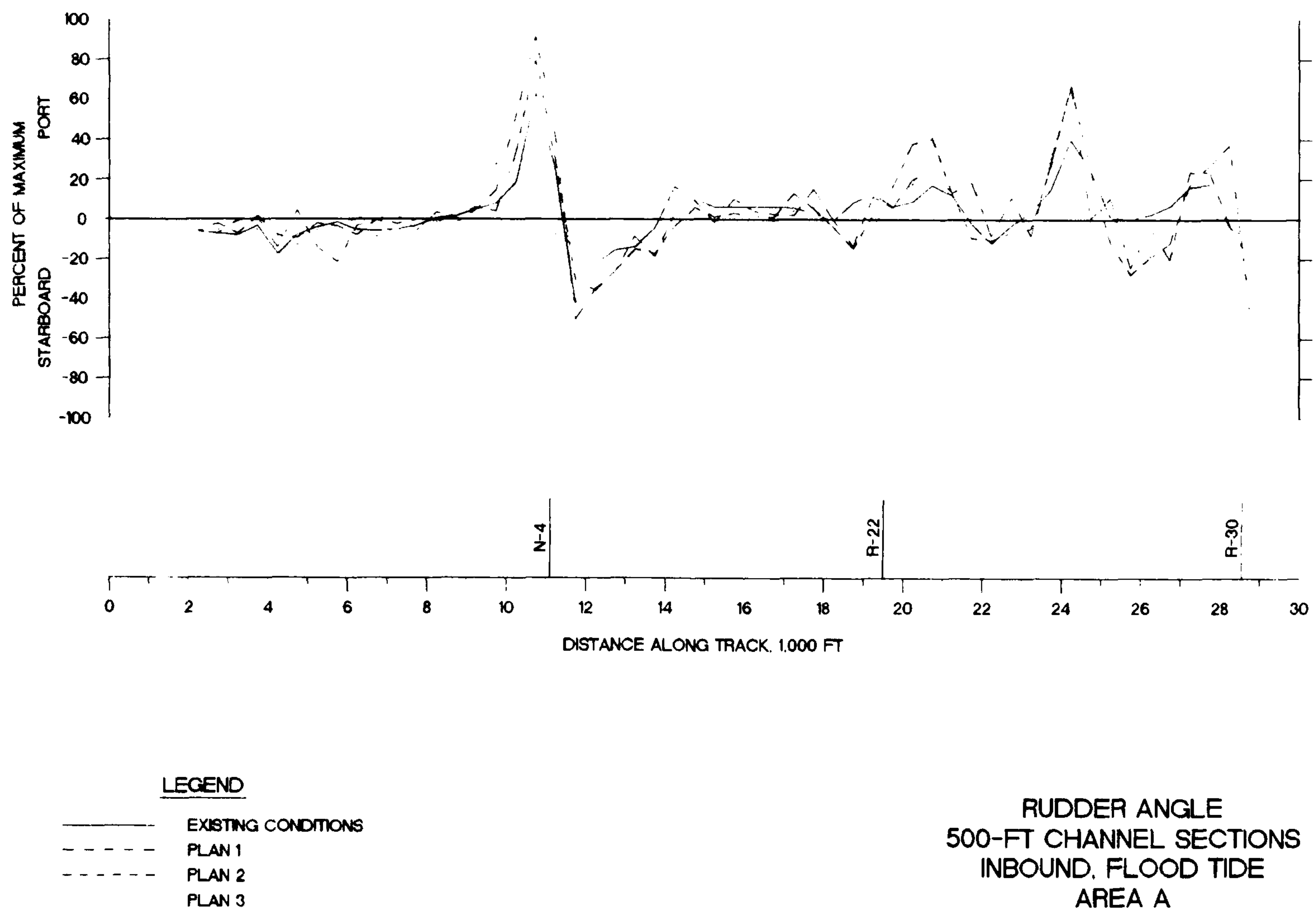


MINIMUM CHANNEL EDGE CLEARANCE
500-FT CHANNEL SECTIONS
INBOUND, EBB TIDE
AREA A
PORT
STARBOARD
CLEARANCE IN FEET
CLEARANCE IN FEET
DISTANCE ALONG TRACK, 1,000 FT
N-4
R-22
R-30
LEGEND
EXISTING CONDITIONS
PLAN 1
PLAN 2
PLAN 3

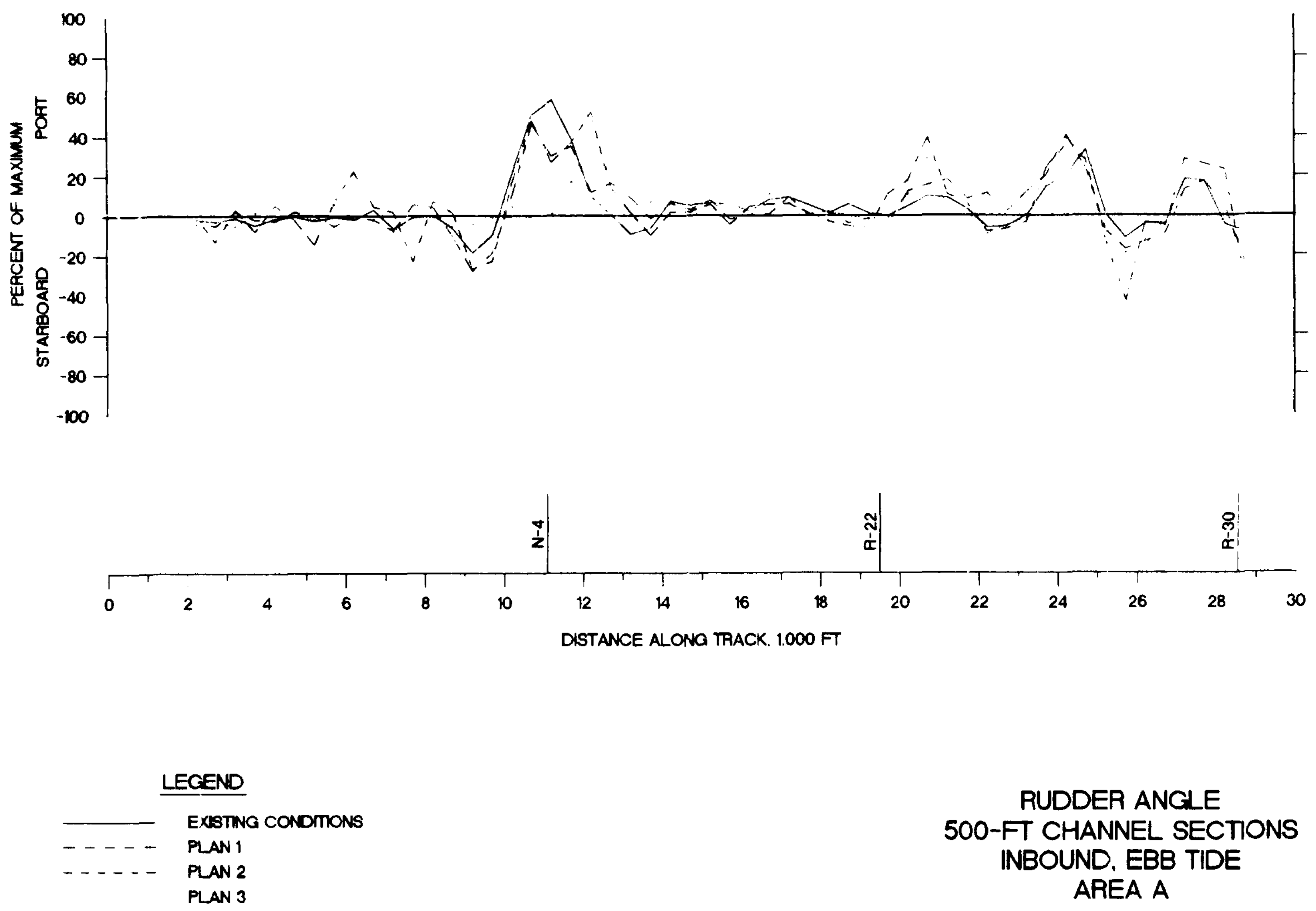


MINIMUM CHANNEL EDGE CLEARANCE
500-FT CHANNEL SECTIONS
OUTBOUND, FLOOD TIDE
AREA A

PLATE 34



RUDDER ANGLE
500-FT CHANNEL SECTIONS
INBOUND, FLOOD TIDE
AREA A



RUDDER ANGLE
500-FT CHANNEL SECTIONS
INBOUND, EBB TIDE
AREA A

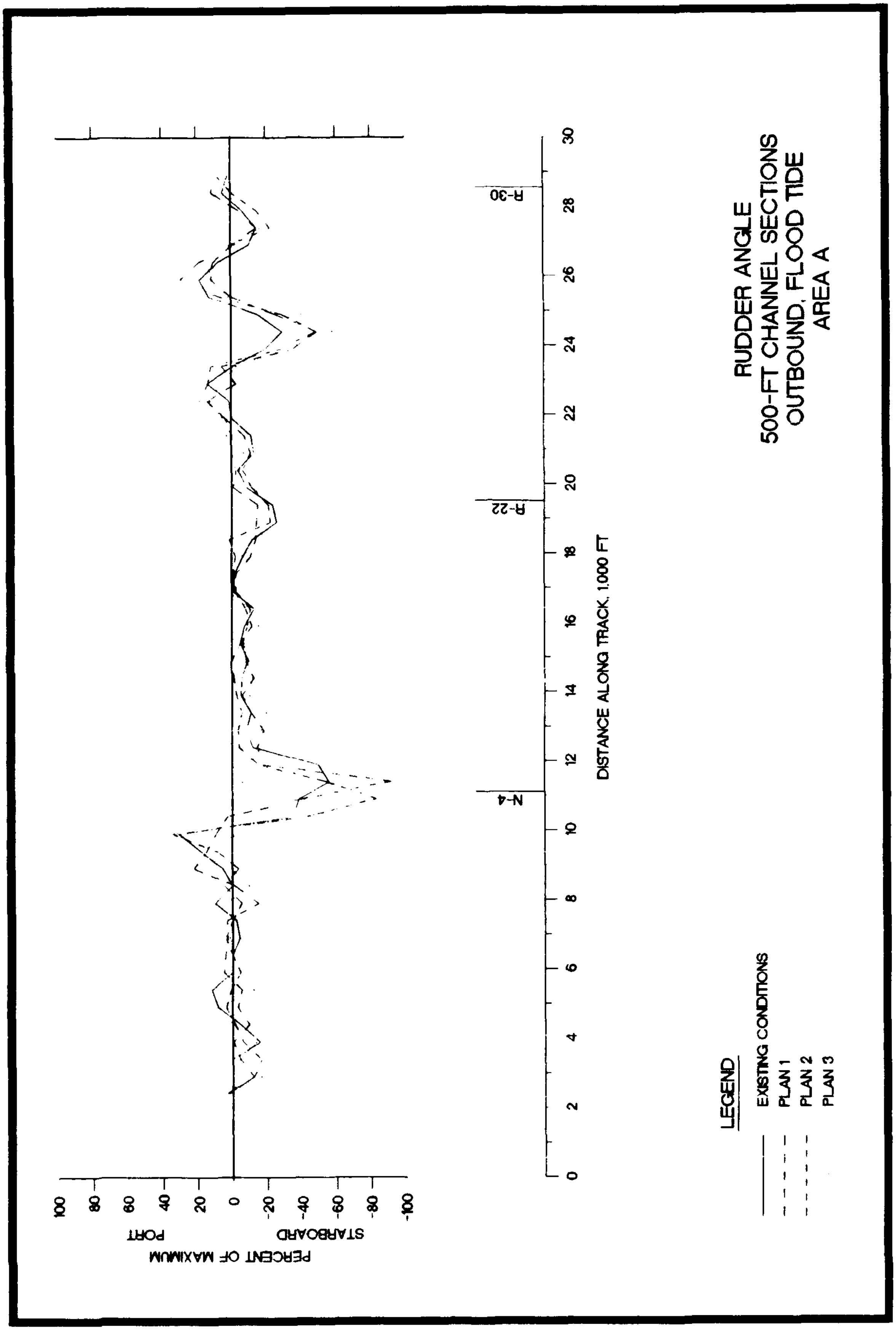

RUDDER ANGLE
500-FT CHANNEL SECTIONS
OUTBOUND, FLOOD TIDE
AREA A
PERCENT OF MAXIMUM
PORT
STARBOARD
100
80
60
40
20
0
-20
-40
-60
-80
-100
DISTANCE ALONG TRACK, 1,000 FT
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
N-4
R-22
R-30
LEGEND
EXISTING CONDITIONS
PLAN 1
PLAN 2
PLAN 3

PLATE 37

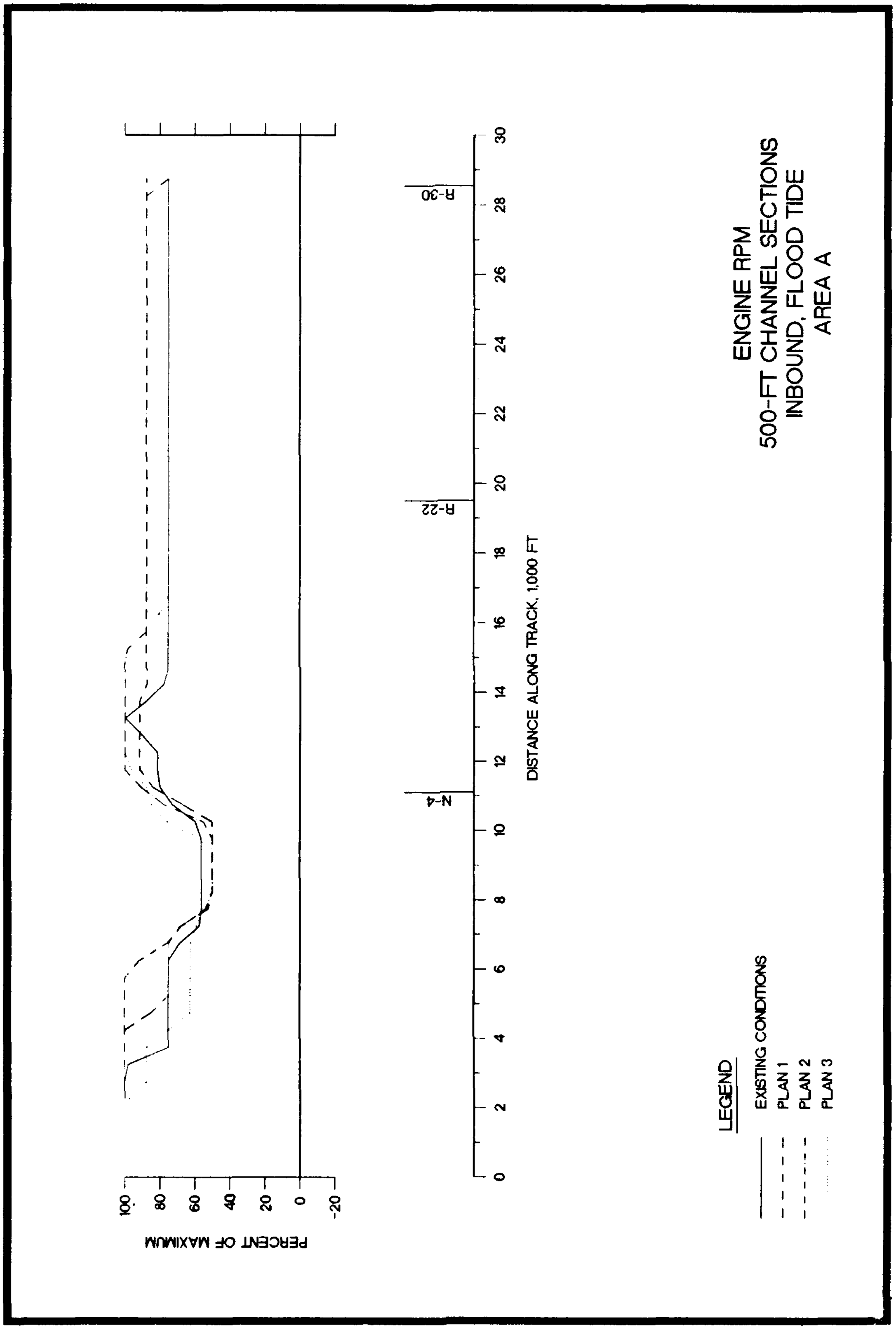
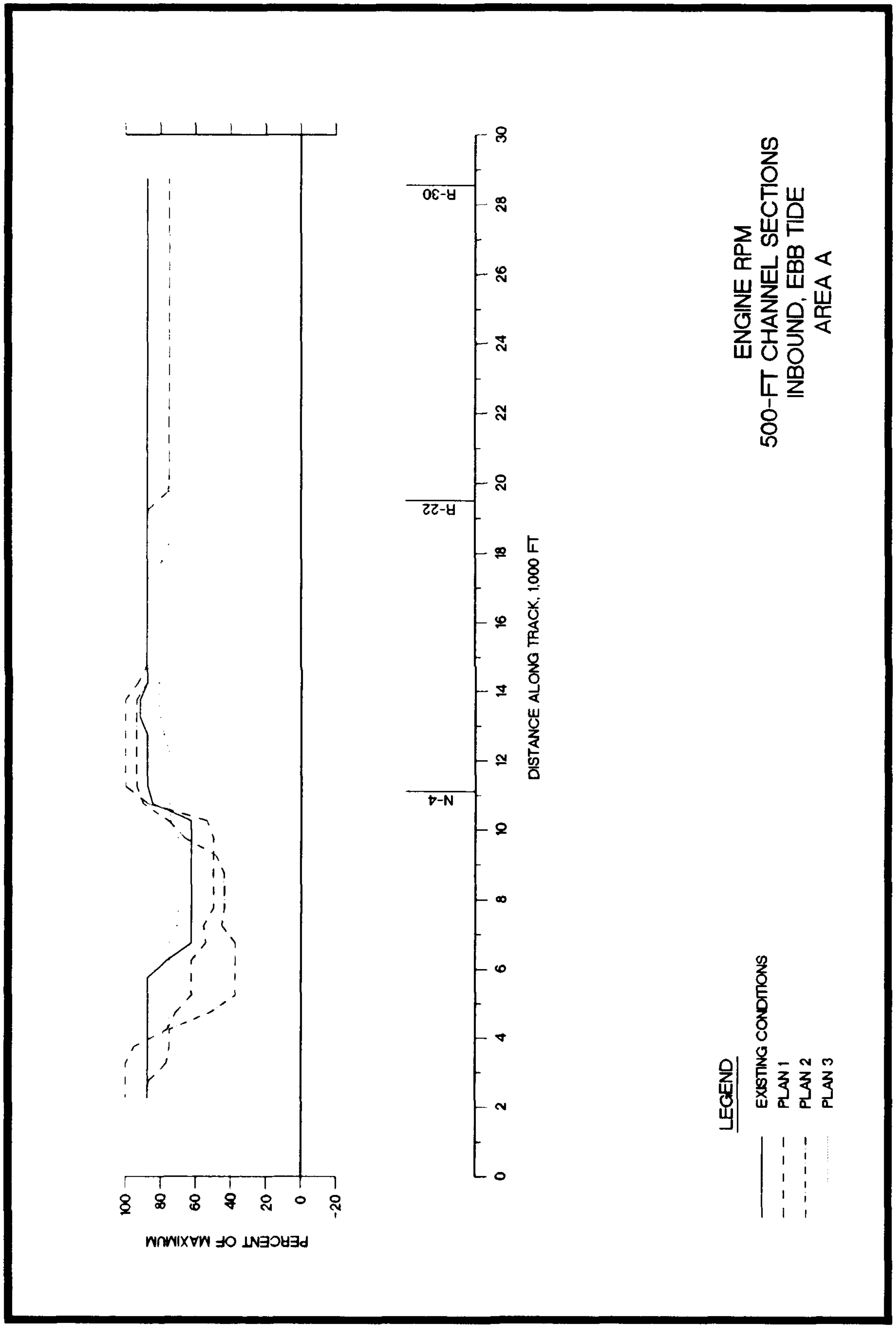
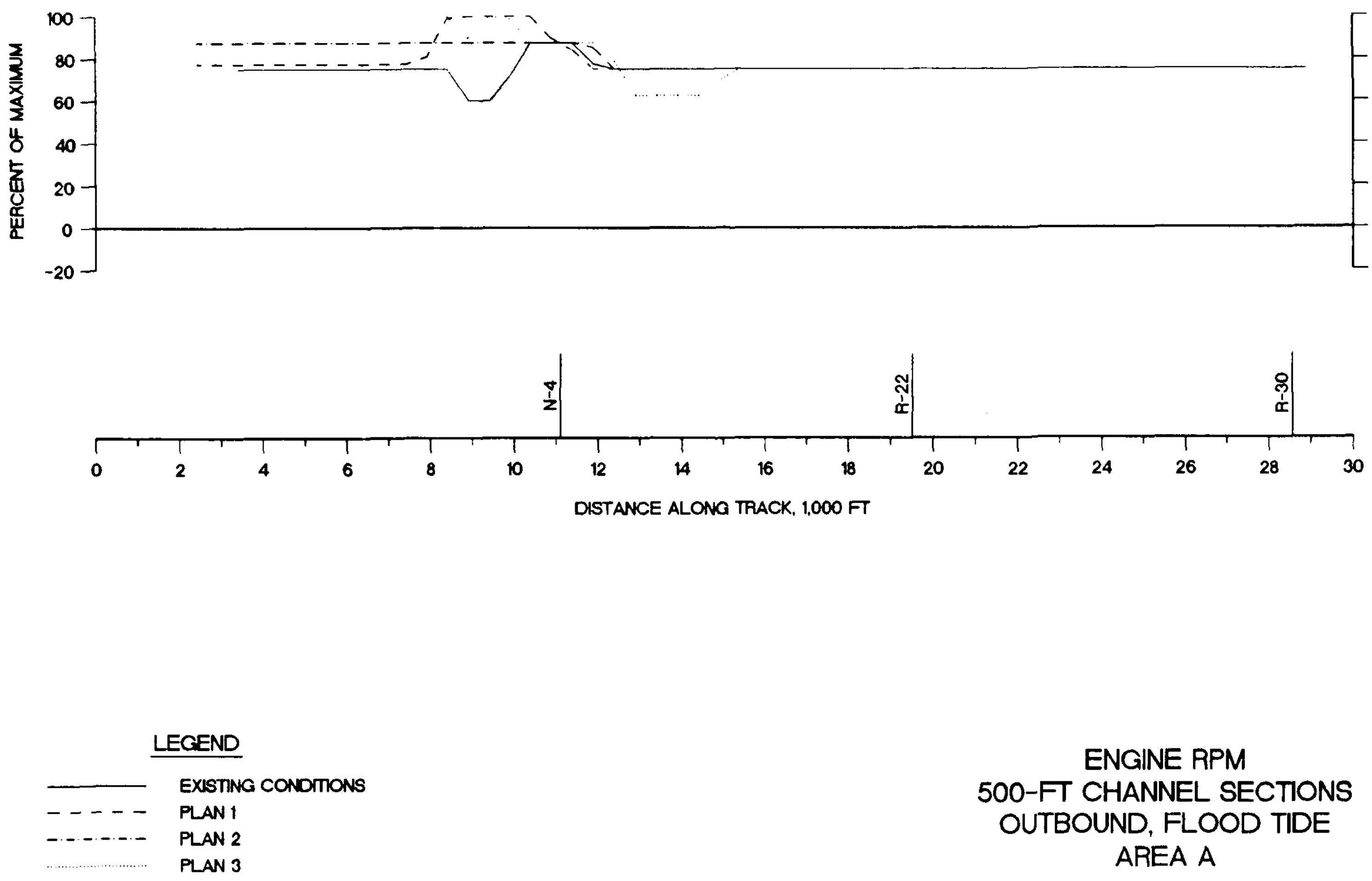
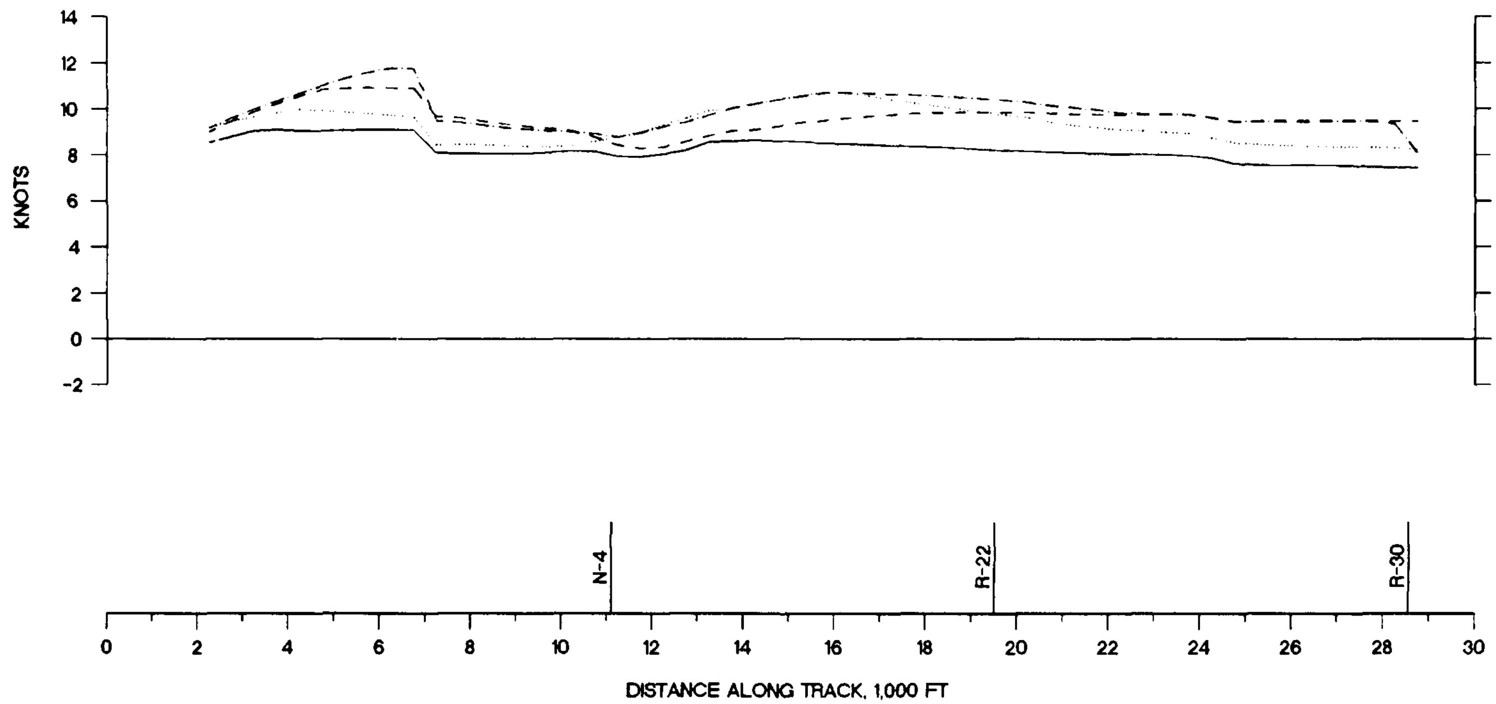

ENGINE RPM
500-FT CHANNEL SECTIONS
INBOUND, FLOOD TIDE
AREA A
PERCENT OF MAXIMUM
100
80
60
40
20
0
-20
DISTANCE ALONG TRACK, 1,000 FT
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
N-4
R-22
R-30
LEGEND
EXISTING CONDITIONS
PLAN 1
PLAN 2
PLAN 3

PLATE 38


PERCENT OF MAXIMUM
100
80
60
40
20
0
-20
DISTANCE ALONG TRACK, 1,000 FT
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
N-4
R-22
R-30
LEGEND
EXISTING CONDITIONS
PLAN 1
PLAN 2
PLAN 3
ENGINE RPM
500-FT CHANNEL SECTIONS
INBOUND, EBB TIDE
AREA A



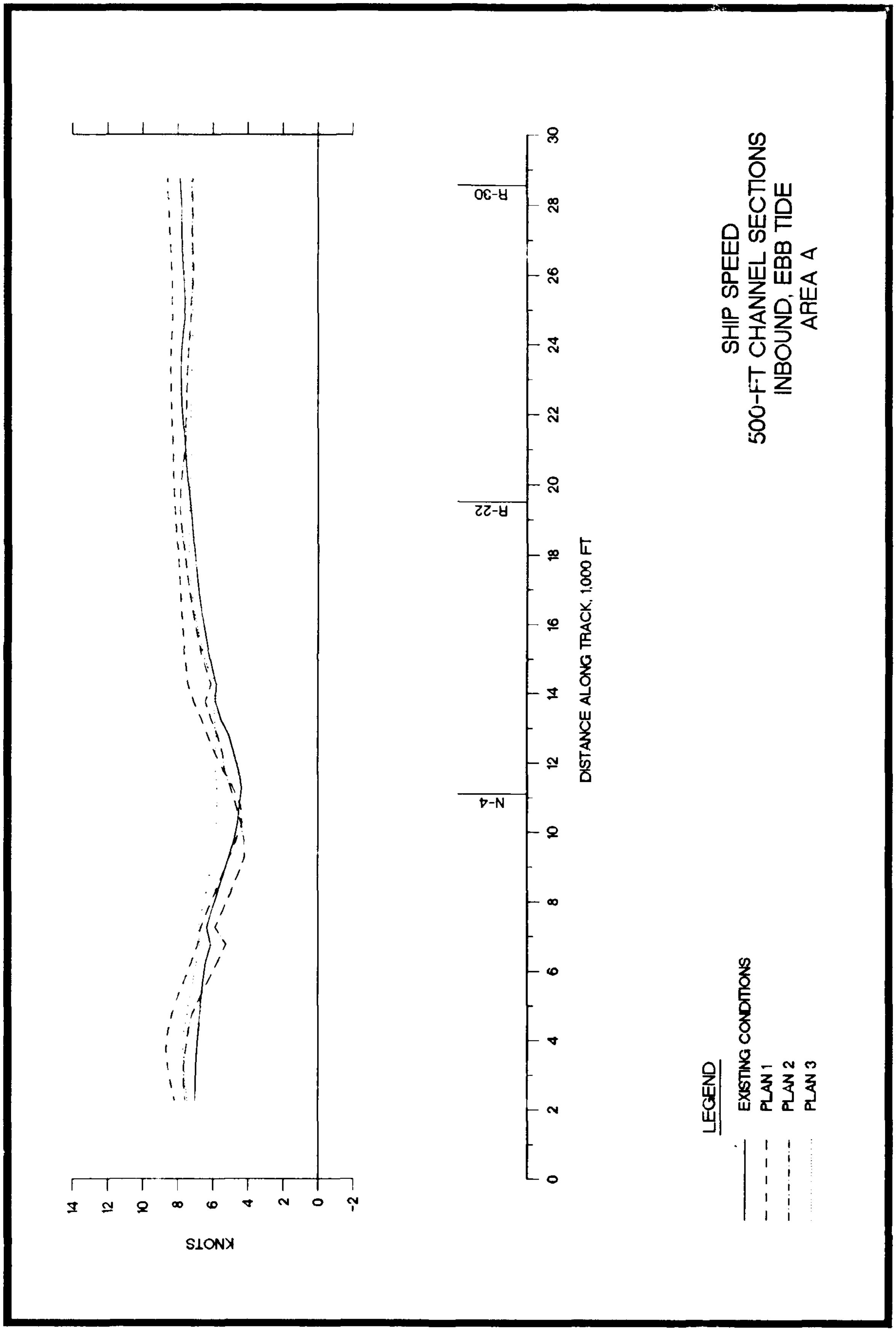
ENGINE RPM
500-FT CHANNEL SECTIONS
OUTBOUND, FLOOD TIDE
AREA A



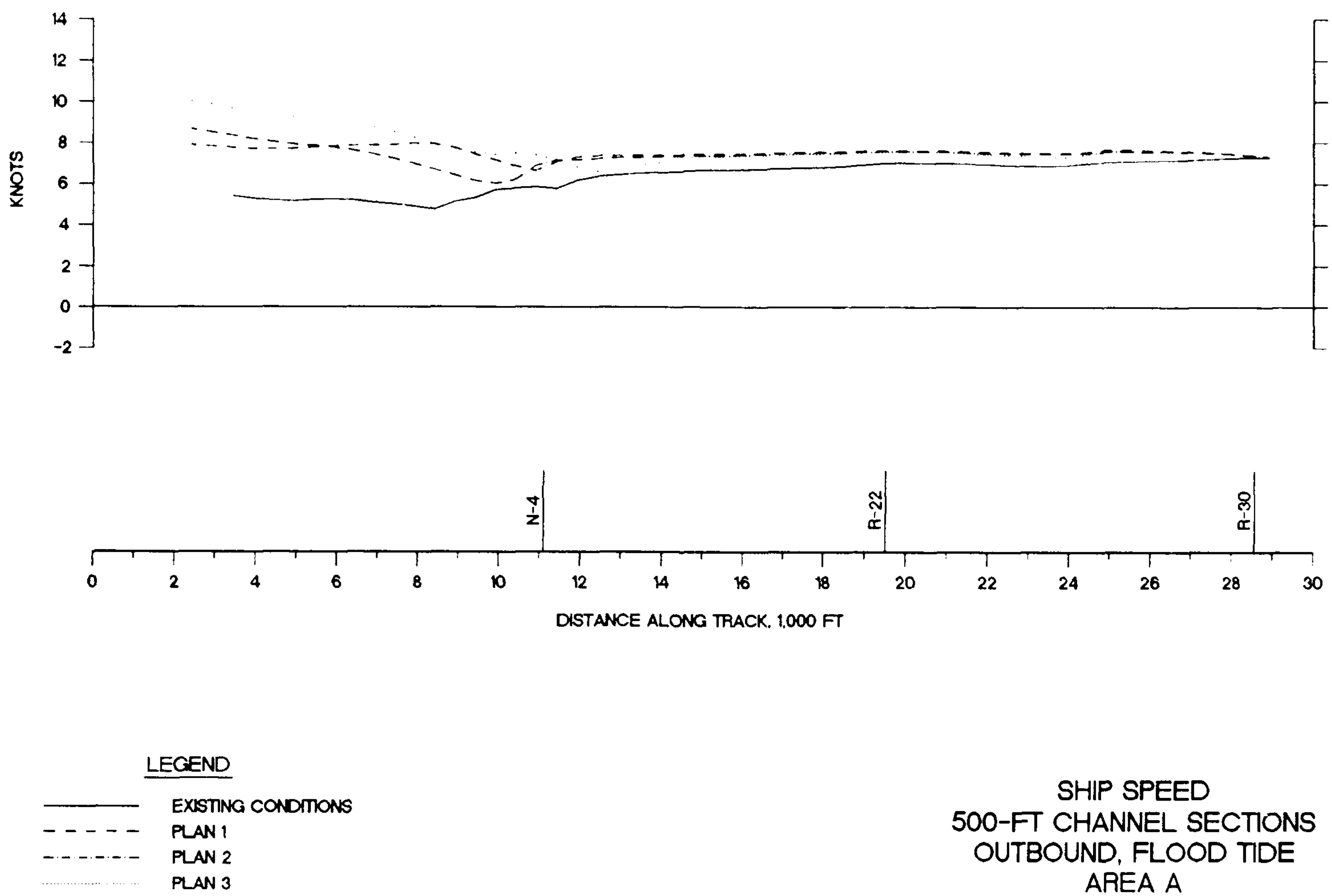
LEGEND

EXISTING CONDITIONS
PLAN 1
PLAN 2
PLAN 3

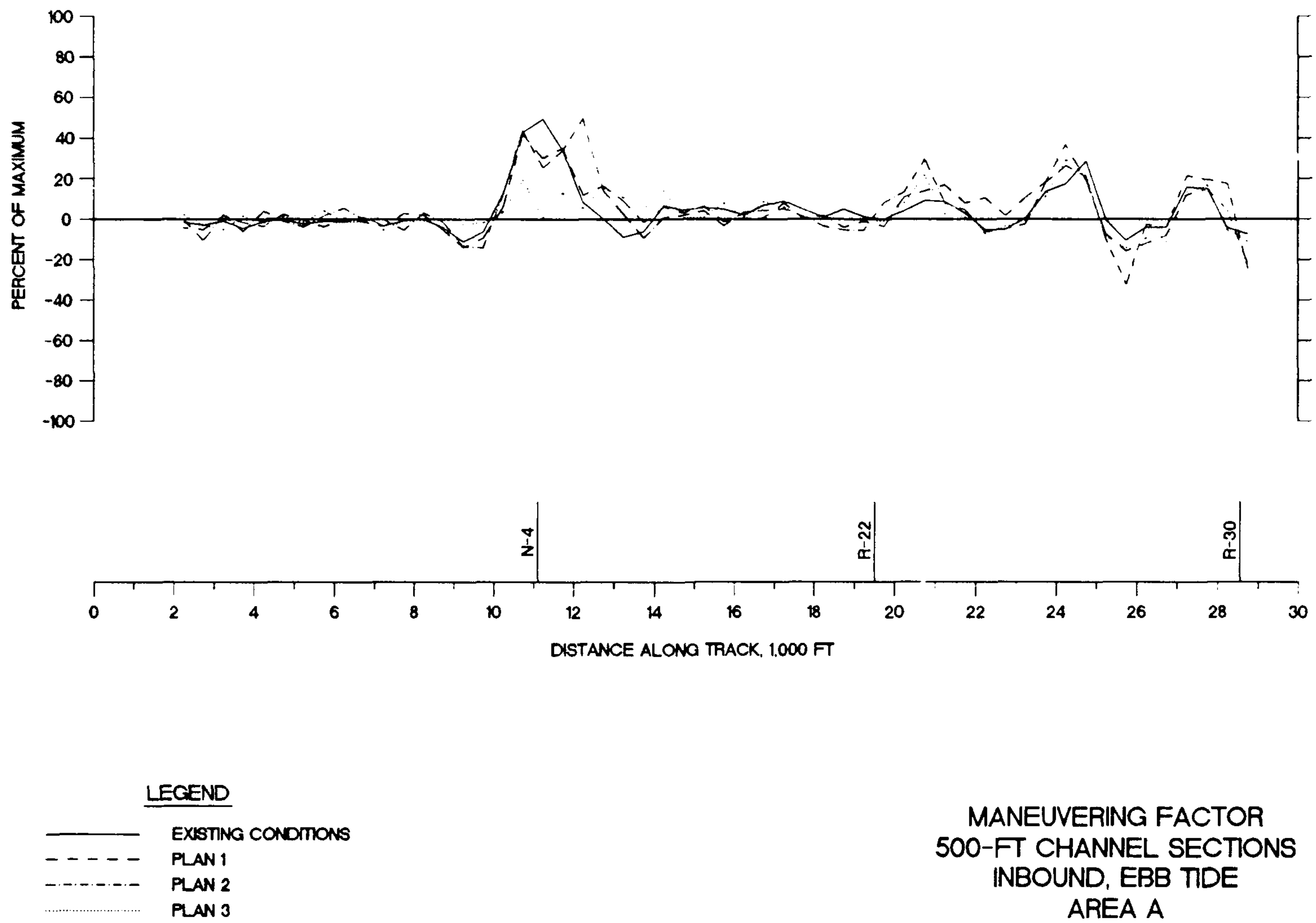
SHIP SPEED
500-FT CHANNEL SECTIONS
INBOUND, FLOOD TIDE
AREA A



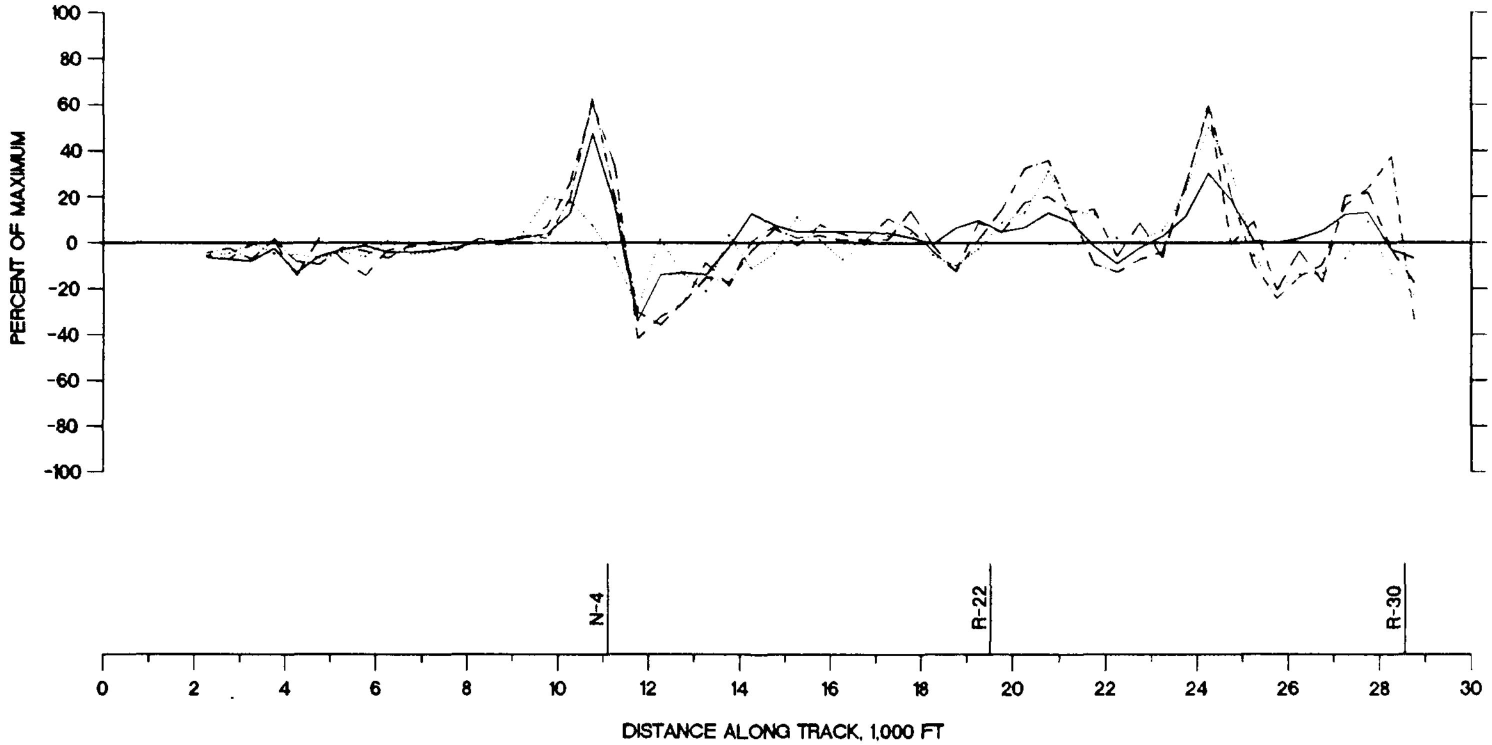
SHIP SPEED
500-FT CHANNEL SECTIONS
INBOUND, EBB TIDE
AREA A



SHIP SPEED
500-FT CHANNEL SECTIONS
OUTBOUND, FLOOD TIDE
AREA A



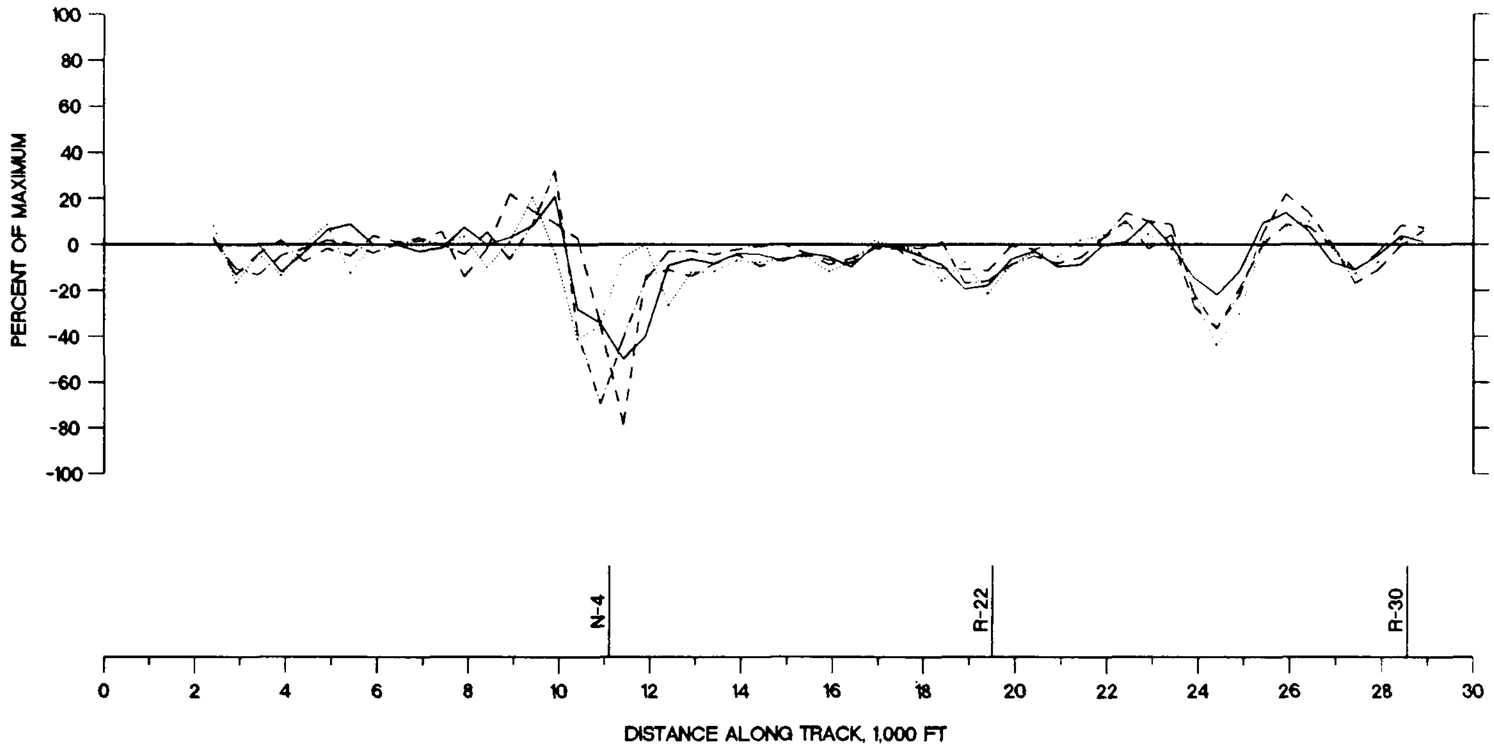
MANEUVERING FACTOR
500-FT CHANNEL SECTIONS
INBOUND, EBB TIDE
AREA A



LEGEND

EXISTING CONDITIONS
PLAN 1
PLAN 2
PLAN 3

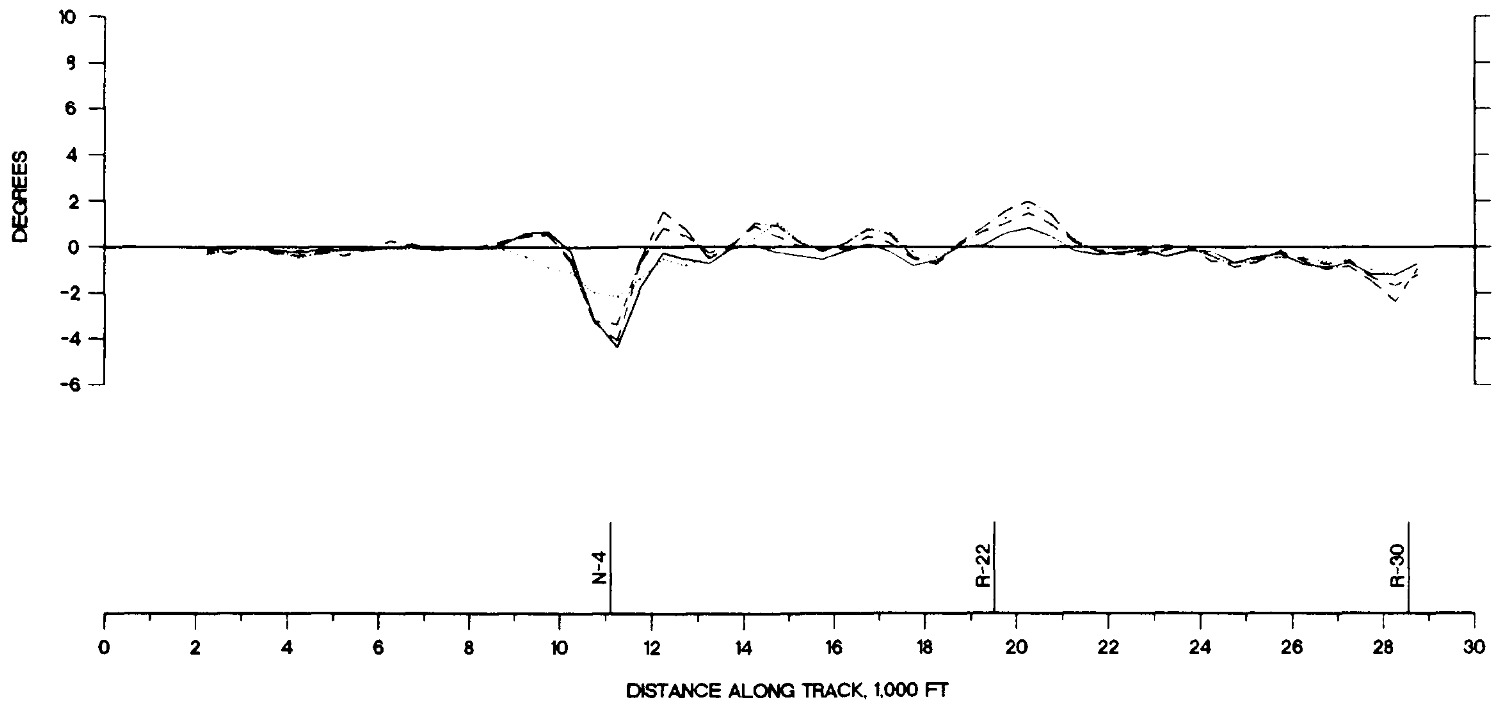
MANEUVERING FACTOR
500-FT CHANNEL SECTIONS
INBOUND, FLOOD TIDE
AREA A



LEGEND

- EXISTING CONDITIONS
- PLAN 1
- PLAN 2
- PLAN 3

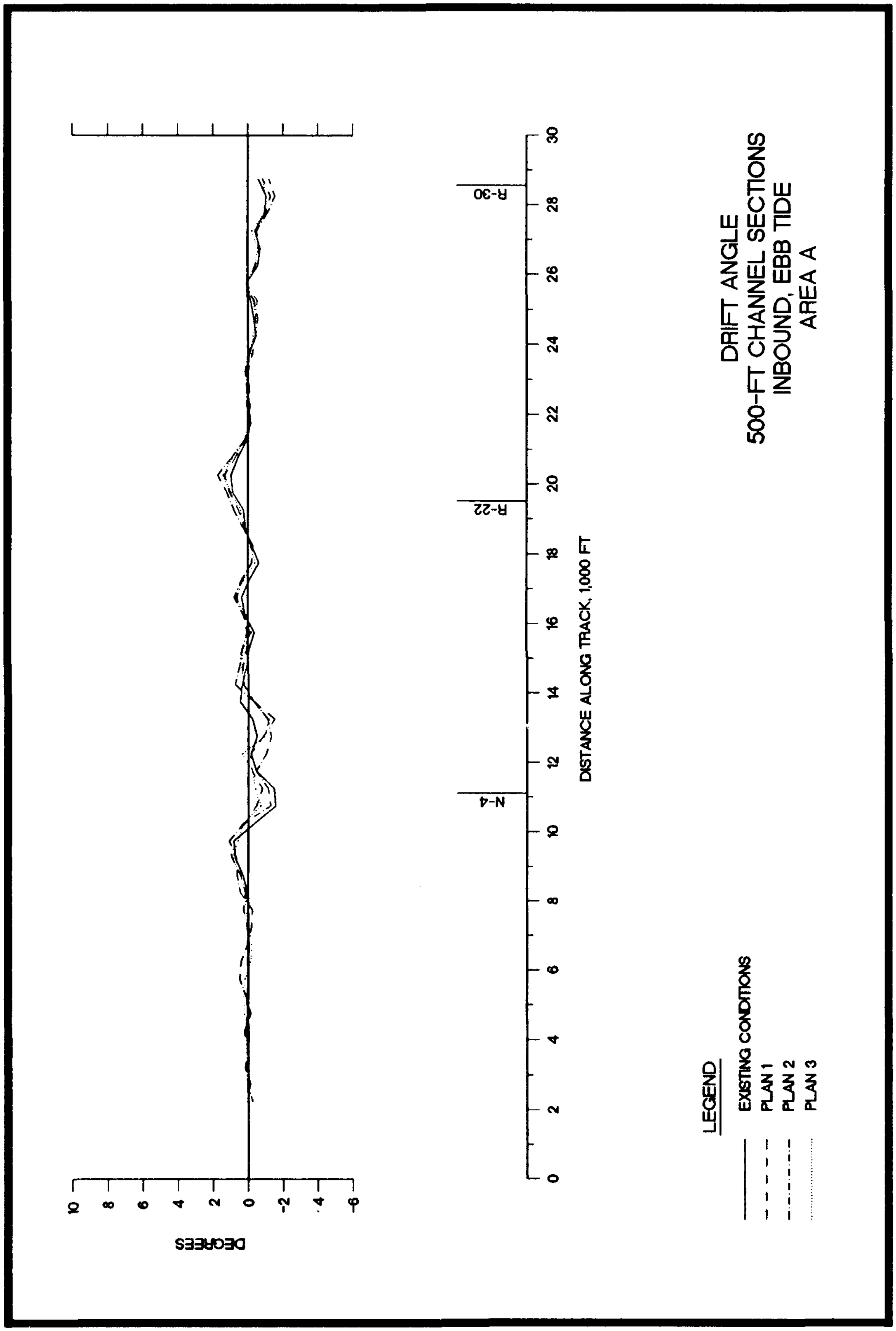
MANEUVERING FACTOR
500-FT CHANNEL SECTIONS
OUTBOUND, FLOOD TIDE
AREA A

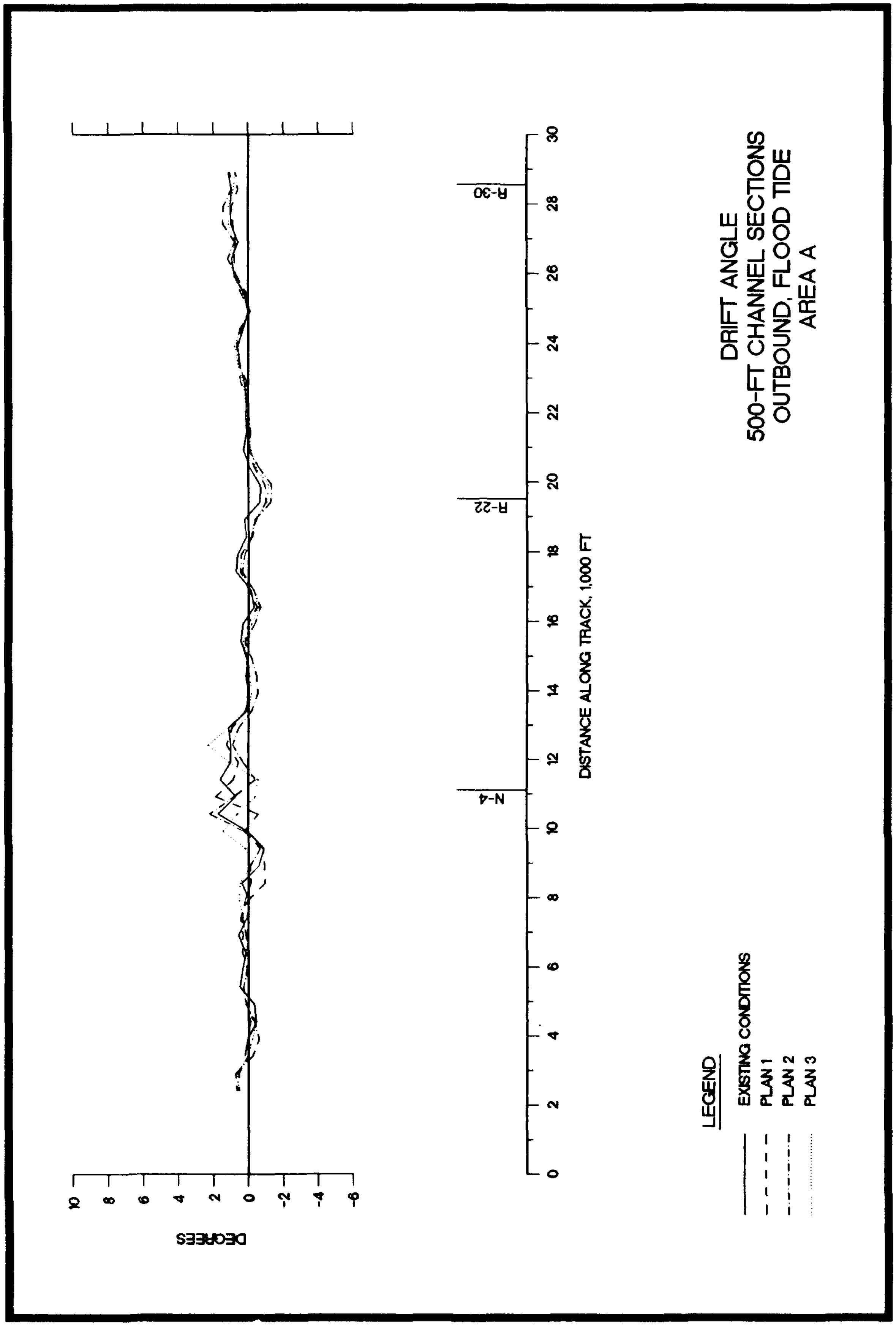


LEGEND

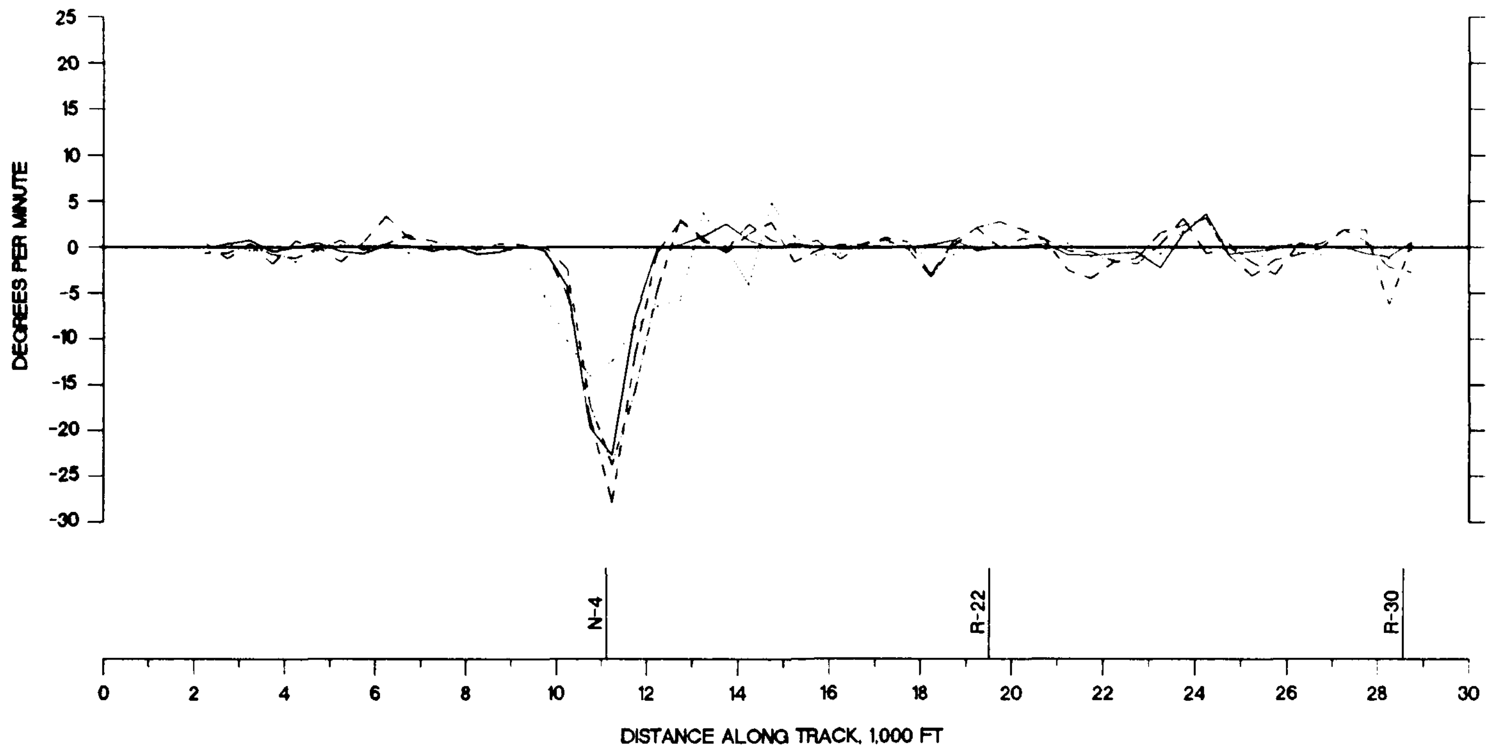
EXISTING CONDITIONS
PLAN 1
PLAN 2
PLAN 3

DRIFT ANGLE
500-FT CHANNEL SECTIONS
INBOUND, FLOOD TIDE
AREA A


DRIFT ANGLE
500-FT CHANNEL SECTIONS
INBOUND, EBB TIDE
AREA A
DEGREES
10
8
6
4
2
0
-2
-4
-6
DISTANCE ALONG TRACK, 1,000 FT
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
N-4
R-22
R-30
LEGEND
EXISTING CONDITIONS
PLAN 1
PLAN 2
PLAN 3



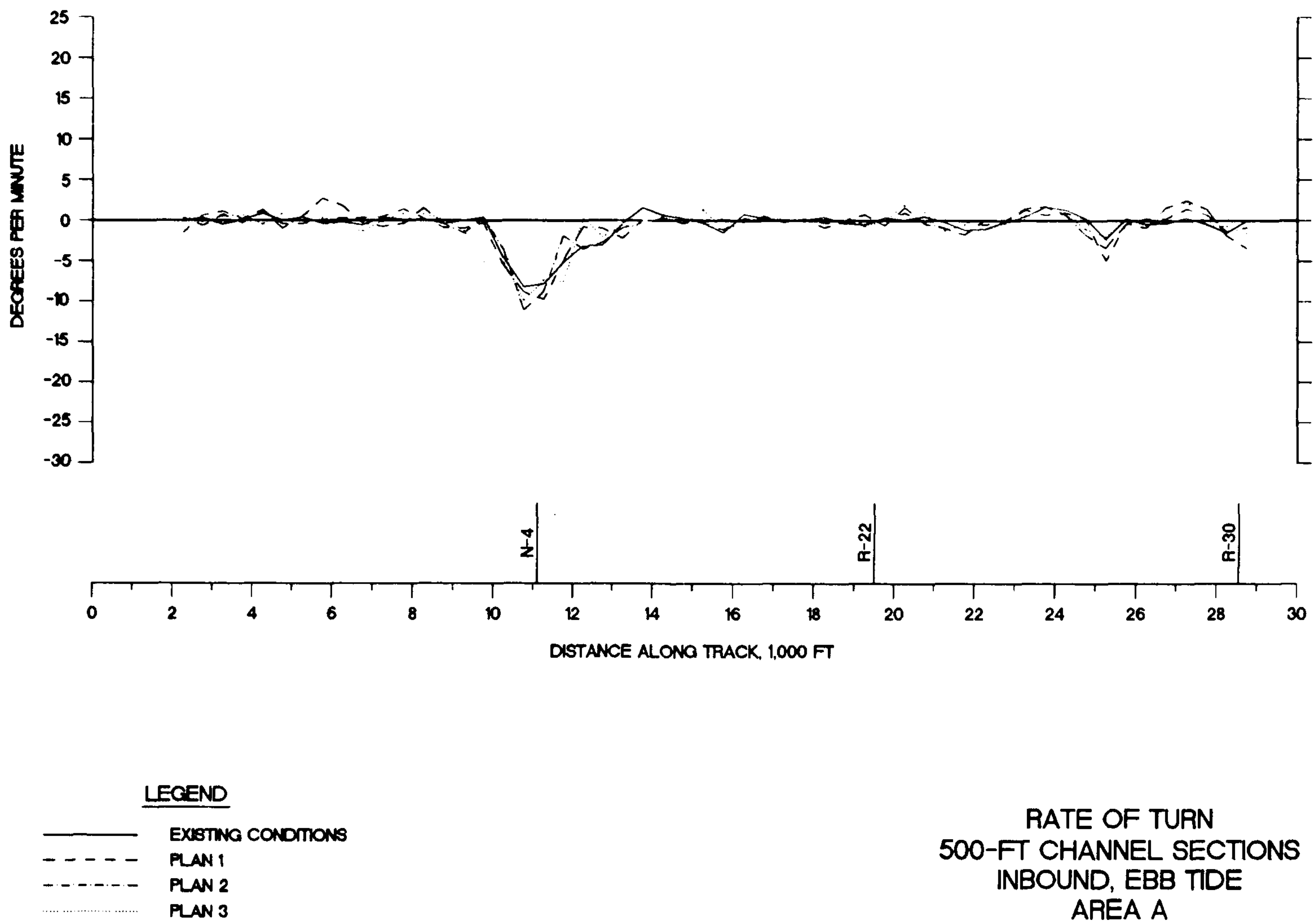
DRIFT ANGLE
500-FT CHANNEL SECTIONS
OUTBOUND, FLOOD TIDE
AREA A
DEGREES
10
8
6
4
2
0
-2
-4
-6
DISTANCE ALONG TRACK, 1,000 FT
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
N-4
R-22
R-30
LEGEND
EXISTING CONDITIONS
PLAN 1
PLAN 2
PLAN 3



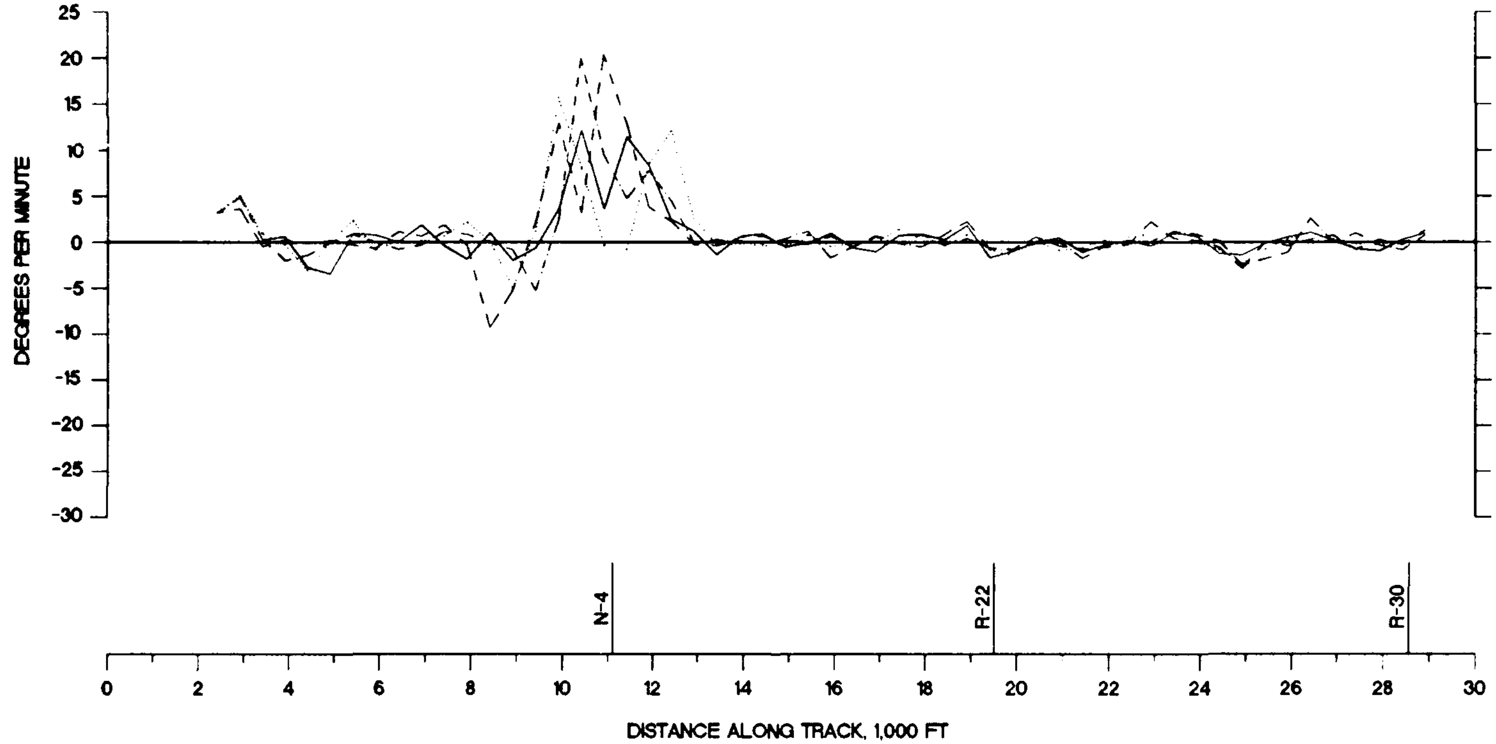
LEGEND

EXISTING CONDITIONS
PLAN 1
PLAN 2
PLAN 3

RATE OF TURN
500-FT CHANNEL SECTIONS
INBOUND, FLOOD TIDE
AREA A



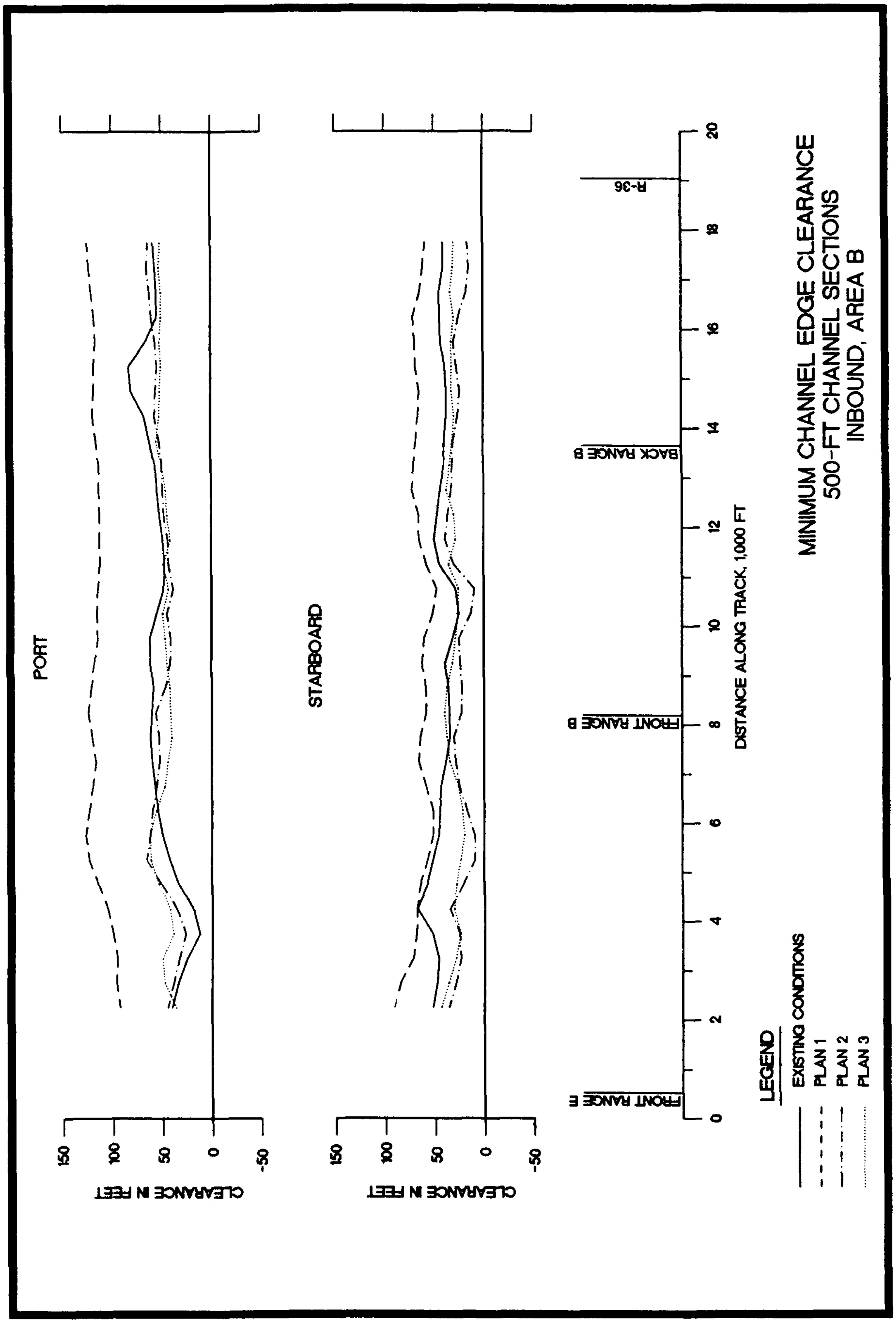
RATE OF TURN
500-FT CHANNEL SECTIONS
INBOUND, EBB TIDE
AREA A



LEGEND

EXISTING CONDITIONS
PLAN 1
PLAN 2
PLAN 3

RATE OF TURN
500-FT CHANNEL SECTIONS
OUTBOUND, FLOOD TIDE
AREA A


PORT
STARBOARD
CLEARANCE IN FEET
150
100
50
0
-50
FRONT RANGE E
FRONT RANGE B
BACK RANGE B
R-36
0
2
4
6
8
10
12
14
16
18
20
DISTANCE ALONG TRACK, 1,000 FT
LEGEND
EXISTING CONDITIONS
PLAN 1
PLAN 2
PLAN 3
MINIMUM CHANNEL EDGE CLEARANCE
500-FT CHANNEL SECTIONS
INBOUND, AREA B

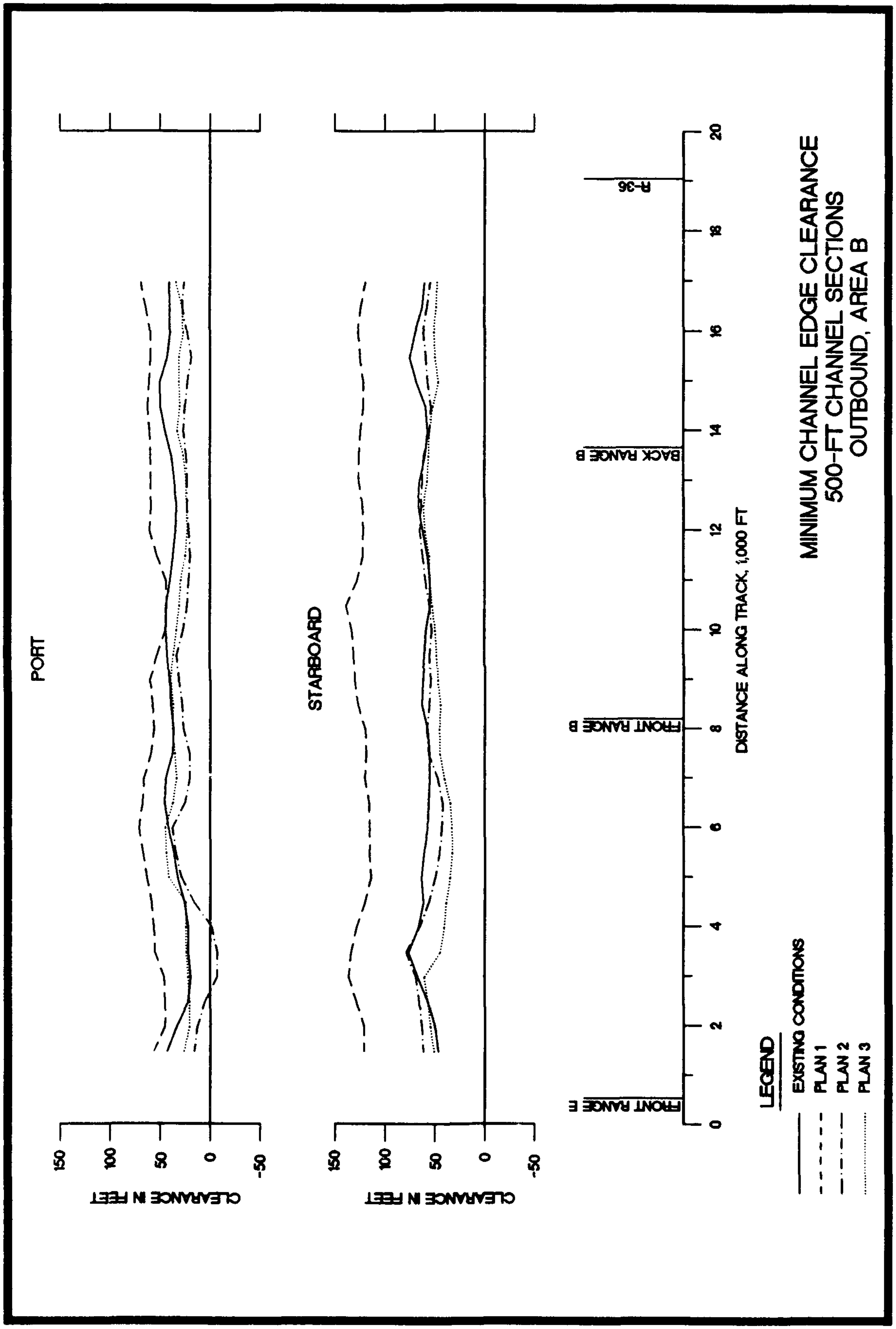
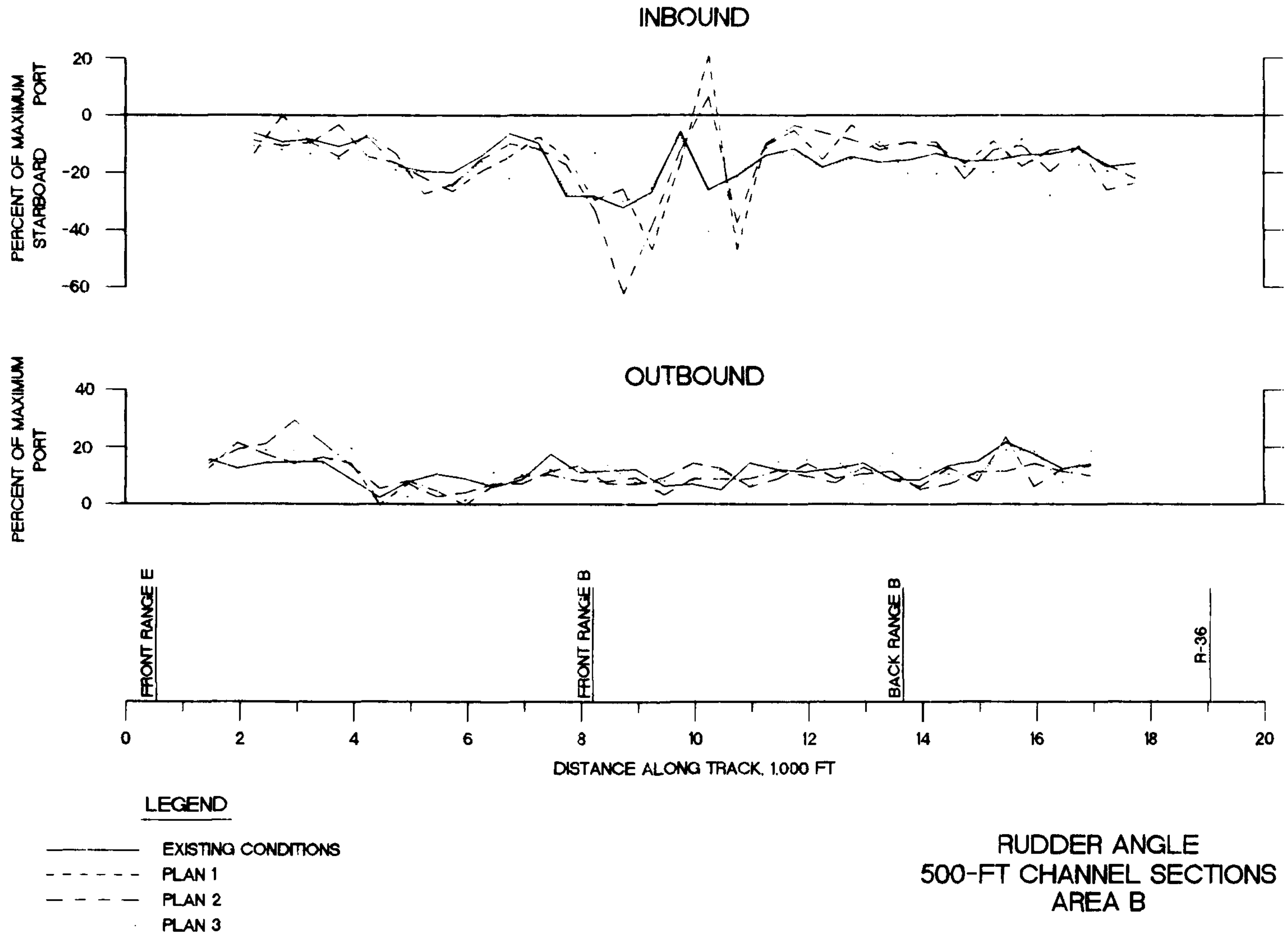
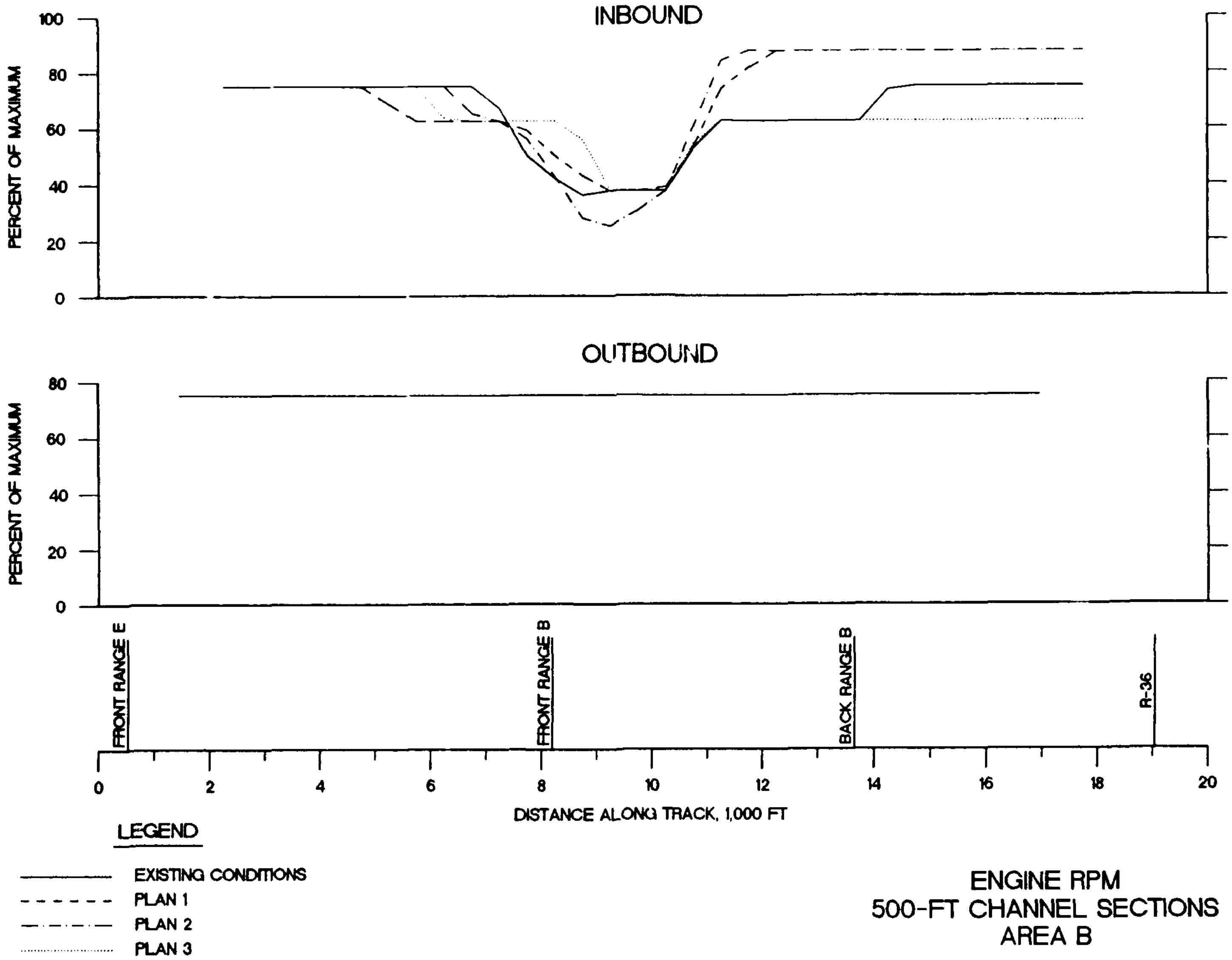

MINIMUM CHANNEL EDGE CLEARANCE
500-FT CHANNEL SECTIONS
OUTBOUND, AREA B
PORT
STARBOARD
CLEARANCE IN FEET
150
100
50
0
-50
DISTANCE ALONG TRACK, 1,000 FT
0
2
4
6
8
10
12
14
16
18
20
FRONT RANGE E
FRONT RANGE B
BACK RANGE B
R-36
LEGEND
EXISTING CONDITIONS
PLAN 1
PLAN 2
PLAN 3

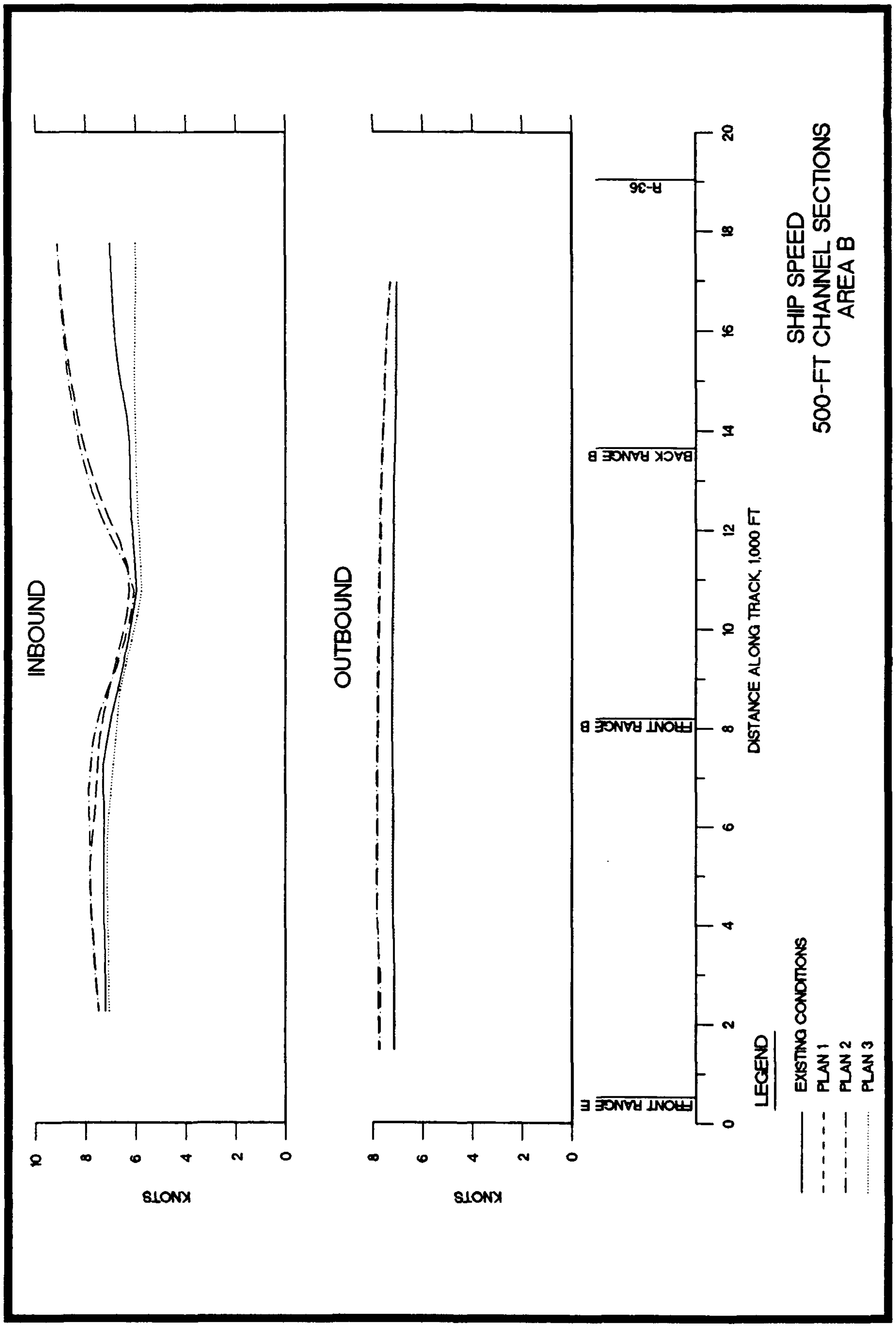
PLATE 54



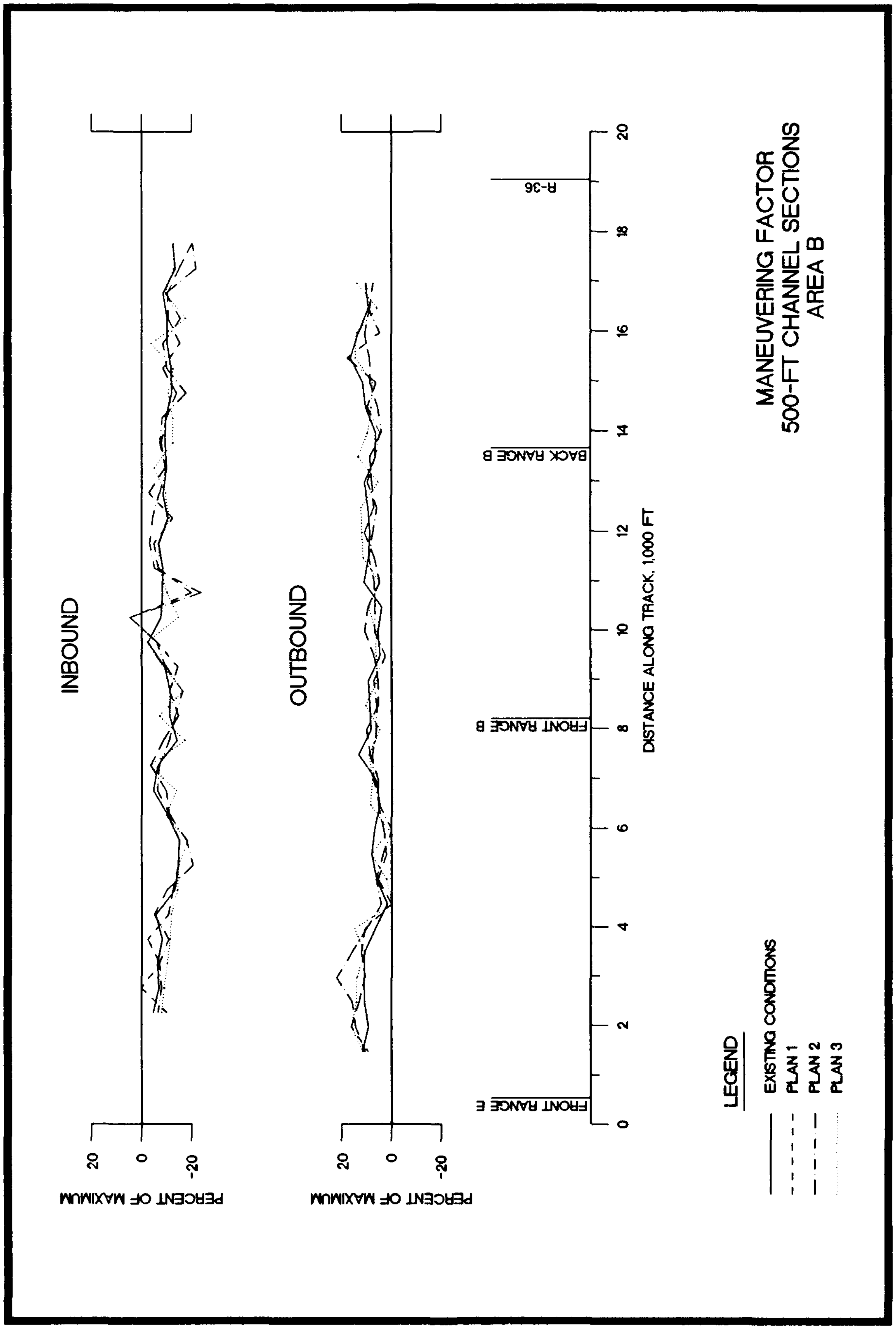
RUDDER ANGLE
500-FT CHANNEL SECTIONS
AREA B



ENGINE RPM
500-FT CHANNEL SECTIONS
AREA B

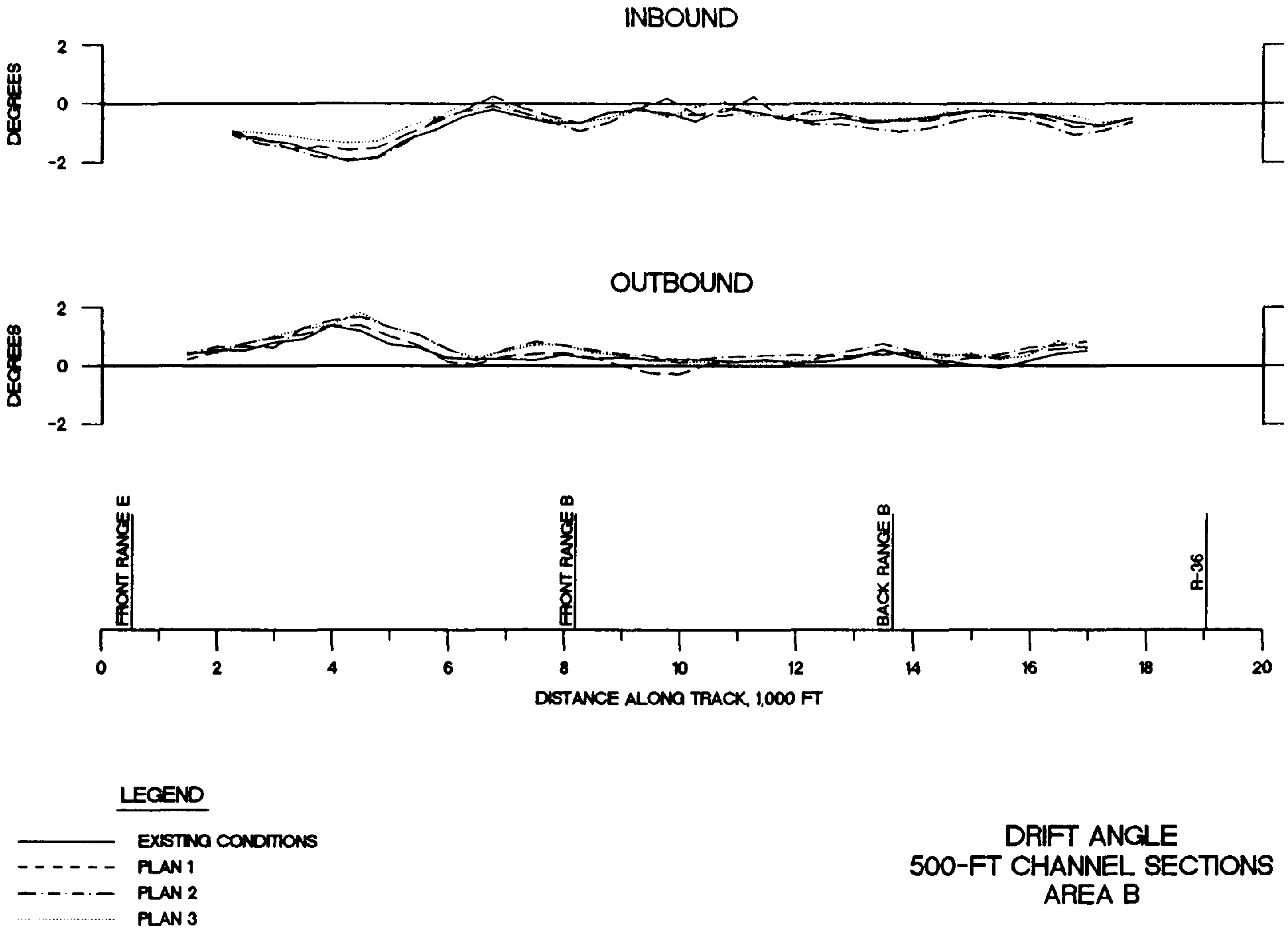


SHIP SPEED
500-FT CHANNEL SECTIONS
AREA B
INBOUND
OUTBOUND
KNOTS
KNOTS
DISTANCE ALONG TRACK, 1,000 FT
FRONT RANGE E
FRONT RANGE B
BACK RANGE B
R-36
LEGEND
EXISTING CONDITIONS
PLAN 1
PLAN 2
PLAN 3

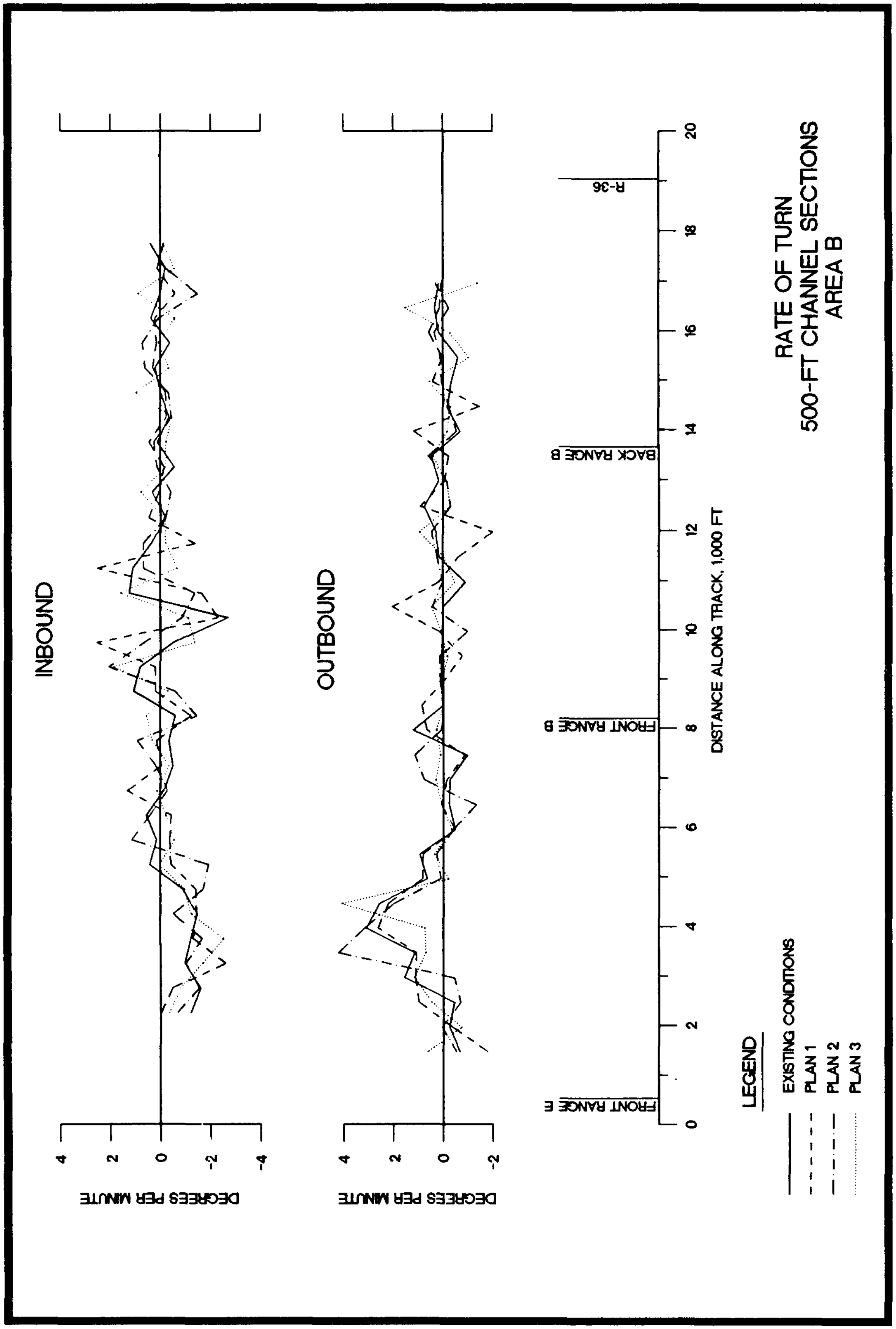


MANEUVERING FACTOR
500-FT CHANNEL SECTIONS
AREA B
INBOUND
OUTBOUND
PERCENT OF MAXIMUM
20
0
-20
PERCENT OF MAXIMUM
20
0
-20
DISTANCE ALONG TRACK, 1,000 FT
0
2
4
6
8
10
12
14
16
18
20
FRONT RANGE E
FRONT RANGE B
BACK RANGE B
R-36
LEGEND
EXISTING CONDITIONS
PLAN 1
PLAN 2
PLAN 3

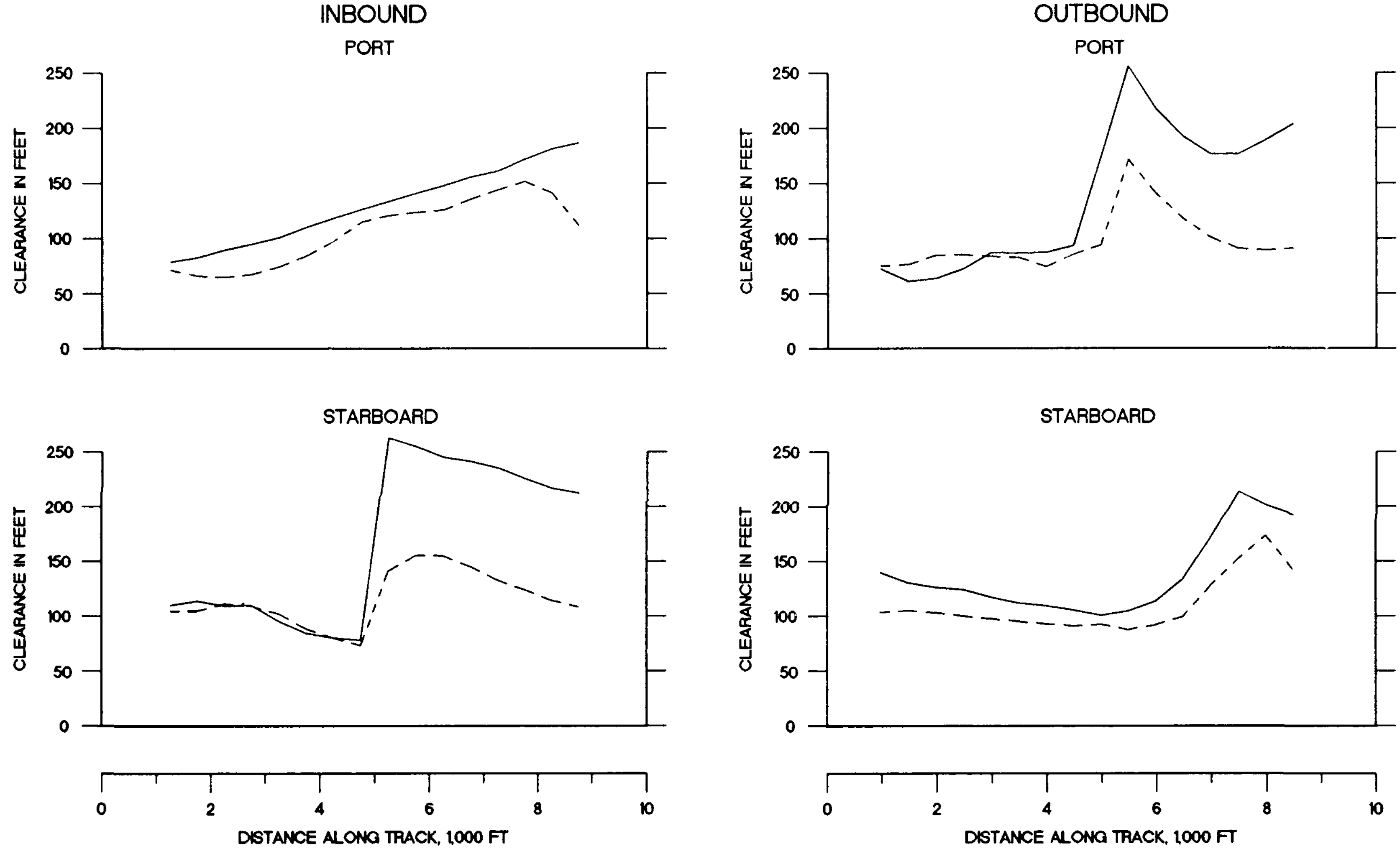
PLATE 58



DRIFT ANGLE
500-FT CHANNEL SECTIONS
AREA B



RATE OF TURN
500-FT CHANNEL SECTIONS
AREA B

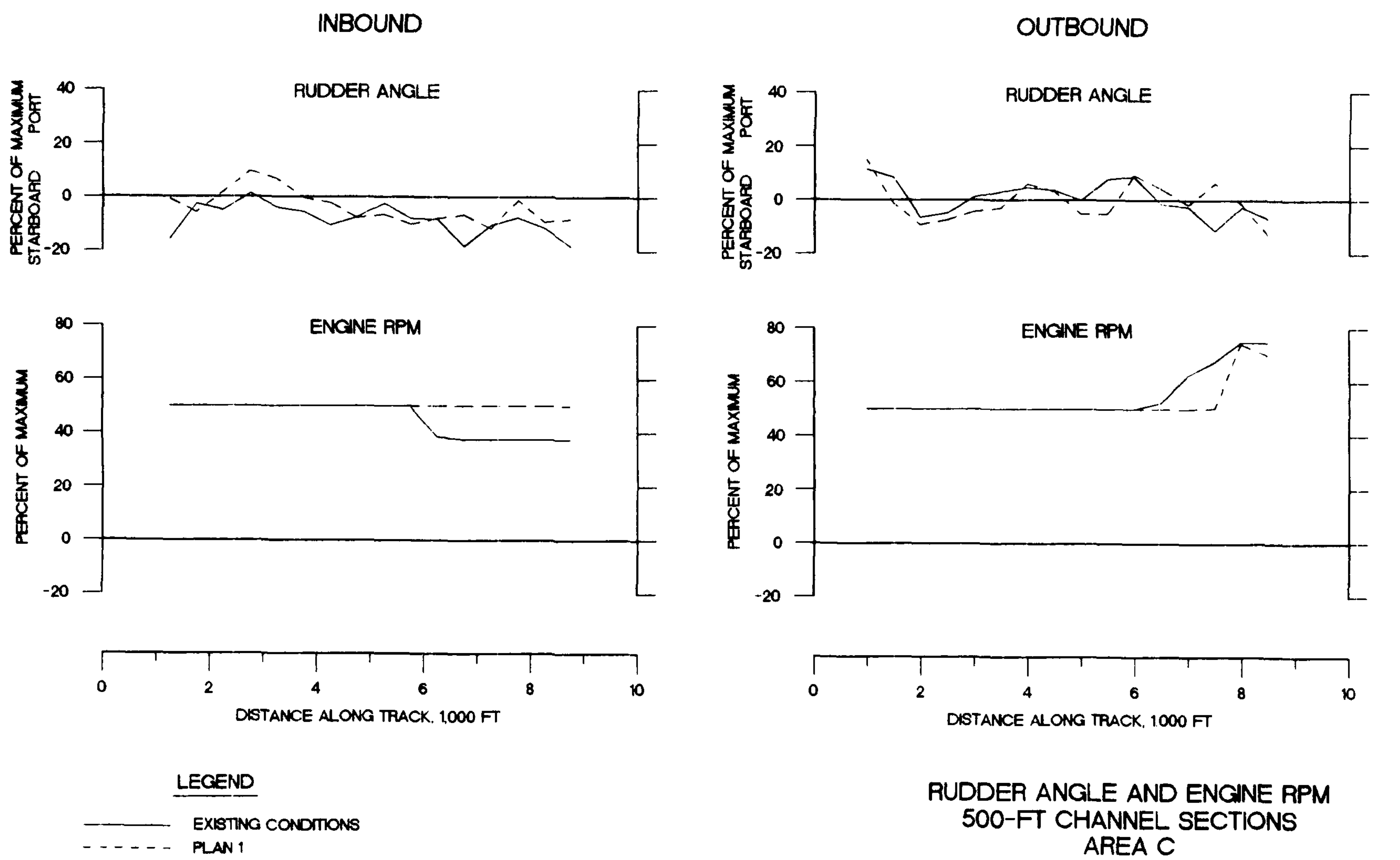


LEGEND

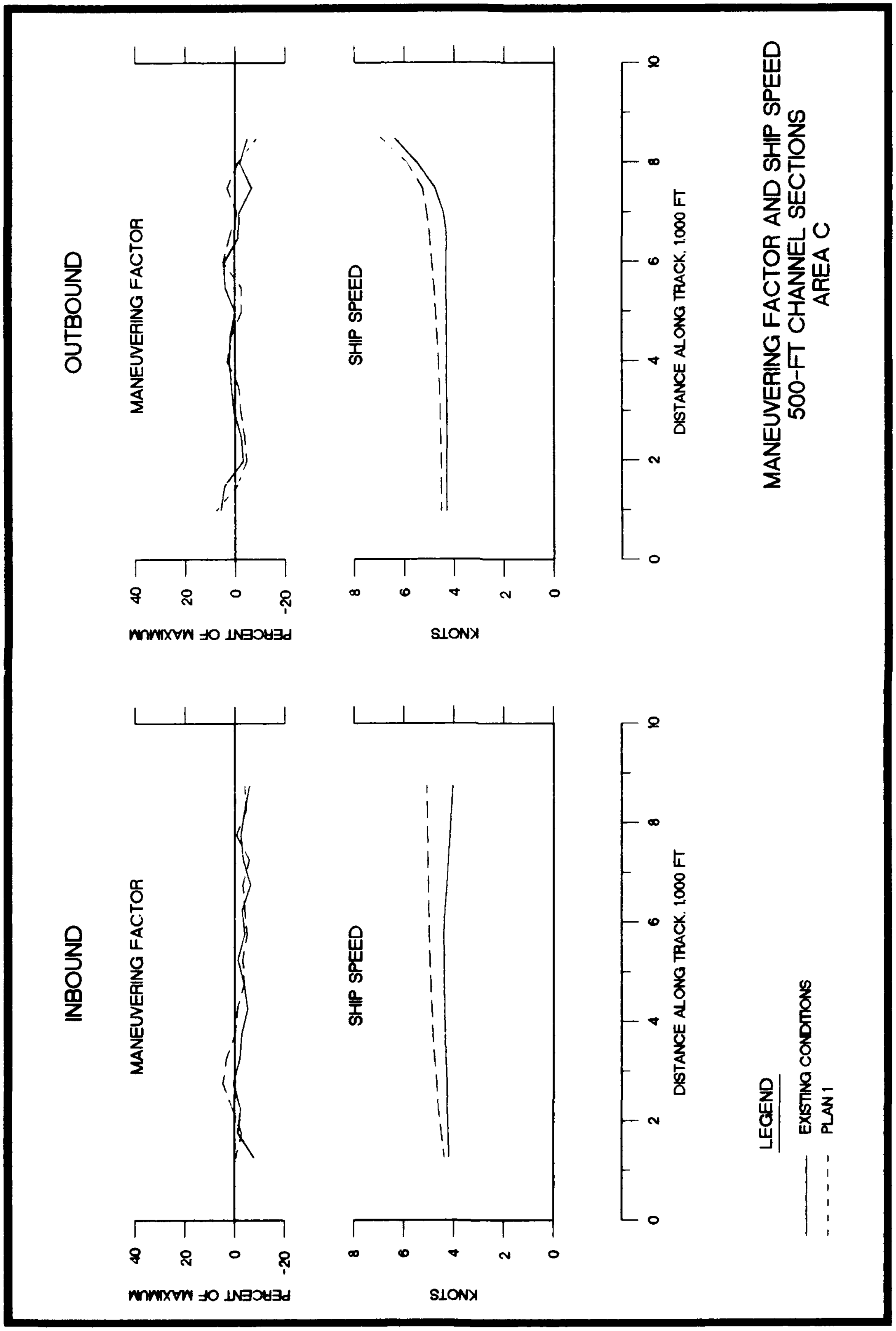
—— EXISTING CONDITIONS

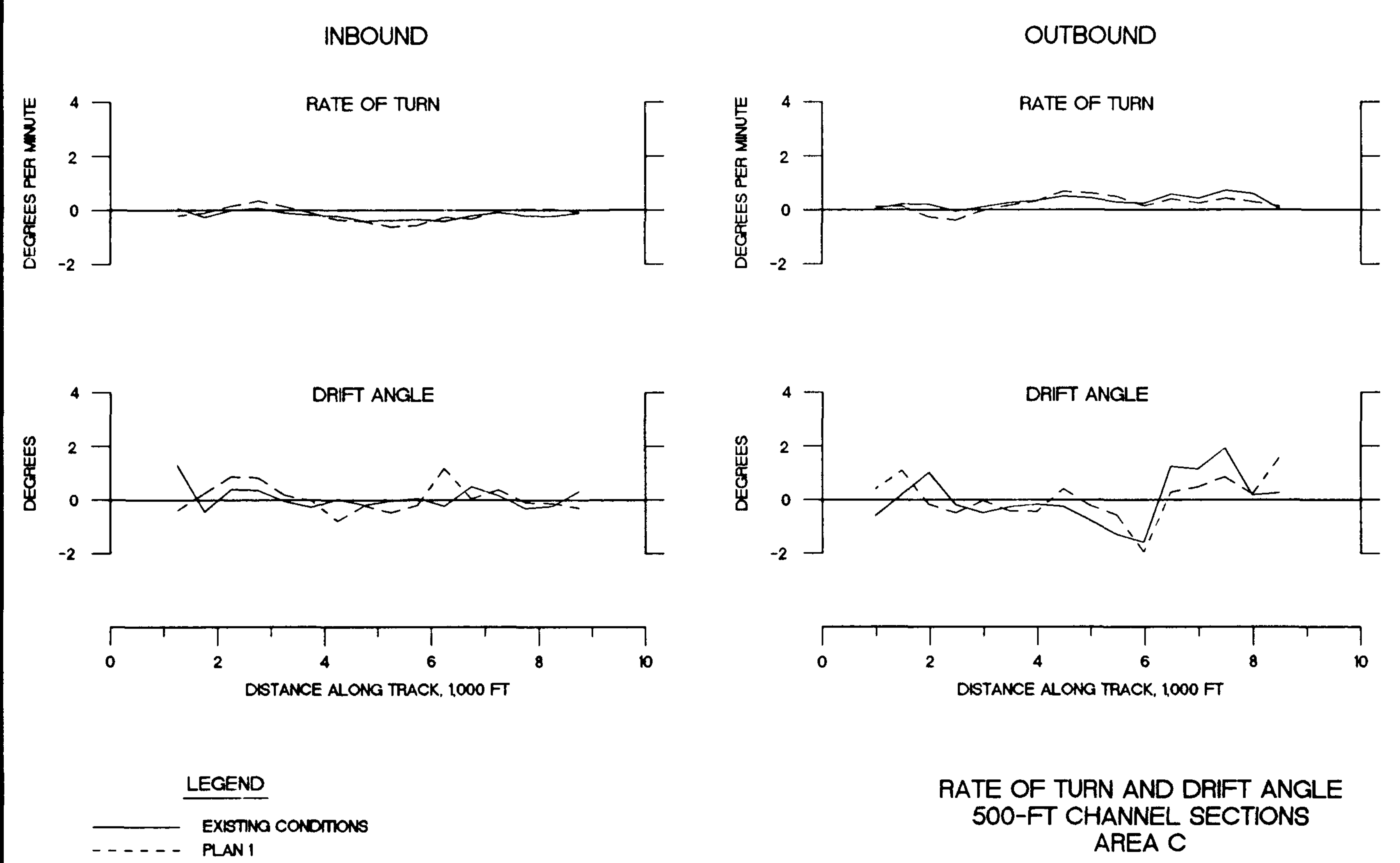
\- - - - PLAN 1

MINIMUM CHANNEL EDGE CLEARANCE
500-FT CHANNEL SECTIONS
AREA C



RUDDER ANGLE AND ENGINE RPM
500-FT CHANNEL SECTIONS
AREA C


INBOUND
OUTBOUND
MANEUVERING FACTOR
PERCENT OF MAXIMUM
40
20
0
-20
SHIP SPEED
KNOTS
8
6
4
2
0
DISTANCE ALONG TRACK, 1,000 FT
0
2
4
6
8
10
LEGEND
EXISTING CONDITIONS
PLAN 1
MANEUVERING FACTOR AND SHIP SPEED
500-FT CHANNEL SECTIONS
AREA C



RATE OF TURN AND DRIFT ANGLE
500-FT CHANNEL SECTIONS
AREA C